

DOC NO
REC'D/FILED

2

UNITED STATES DISTRICT COURT
WESTERN DISTRICT OF WISCONSIN 2006 AUG -4 PM 2:49

THERESA M. OWENS
CLERK US DIST COURT
WD OF WI

KERR CORPORATION,

Plaintiff,

Case No.

vs.

JURY TRIAL DEMANDED

3M COMPANY and
DENTSPLY INTERNATIONAL INC.,

Defendants.

06 C 0423 C

COMPLAINT

The plaintiff, Kerr Corporation ("Kerr"), by its attorneys Michael Best & Friedrich, LLP, for its complaint against 3M Company ("3M") and Dentsply International Inc. ("Dentsply") alleges as follows:

PARTIES

1. Plaintiff Kerr is a corporation incorporated under the laws of the State of Delaware, having its principal place of business at 1717 West Collins Avenue, Orange, California 92867.
2. Defendant 3M is a corporation incorporated under the laws of the State of Delaware, having its principal place of business at 3M Center Building, 220-11W-02, St. Paul, Minnesota 55144-1000.
3. Defendant Dentsply is a corporation incorporated under the laws of the State of Delaware, having its principal place of business at Susquehanna Commerce Center, 221 W. Philadelphia Street, York, Pennsylvania 17405.

JURISDICTION AND VENUE

4. This action arises under the patent laws of the United States, Title 35, United States Code. This court has subject matter jurisdiction pursuant to 28 U.S.C. §§ 1338(a) and 1331.

5. Venue is proper in this judicial district pursuant to 28 U.S.C. §§ 1391(c) and 1400(b).

6. 3M and Dentsply do substantial business in the State of Wisconsin and are subject to personal jurisdiction in the Western District of Wisconsin.

FACTUAL BACKGROUND

7. On February 17, 2004, United States Patent No. 6,692,251 (the “251 patent”) was duly and legally issued to Joseph N. Logan and Raymond L. Knox with the following title: “APPARATUS AND METHOD FOR CURING MATERIALS WITH LIGHT RADIATION.” A copy of the ‘251 patent is attached hereto as **Exhibit A**.

8. By virtue of assignment, Kerr has acquired and continues to maintain all right, title and interest in and to the ‘251 patent.

9. On June 27, 2006, United States Patent No. 7,066,733 (the “733 patent”) was duly and legally issued to Joseph N. Logan and Raymond L. Knox with the following title: “APPARATUS AND METHOD FOR CURING MATERIALS WITH LIGHT RADIATION.” A copy of the ‘733 patent is attached hereto as **Exhibit B**.

10. By virtue of assignment, Kerr has acquired and continues to maintain all right, title and interest in and to the ‘733 patent.

11. 3M manufactures and sells a curing light under the Epilar™ FreeLight 2 brand name.

12. Dentsply manufactures and sells a curing light line of products under the SmartLite™ brand name.

13. Constructive notice of the '251 patent was provided by Kerr through its marking of devices covered by the '251 patent.

14. 3M had actual notice of the '251 patent through correspondence from Kerr in 2004.

15. Dentsply had actual notice of the '251 patent through correspondence from Kerr in 2004.

COUNT 1
(Patent Infringement by 3M of '251 Patent)

16. Paragraphs 1 through 15 are realleged as though fully set forth herein.

17. 3M, without the permission of Kerr, has been and still is manufacturing, selling and offering for sale, within the United States, a device for curing materials with light radiation that infringes on the '251 patent. 3M's actions constitute both direct and indirect infringement of the '251 patent.

18. 3M had actual notice of the '251 patent, and 3M's continued infringement of the '251 patent has been and continues to be willful and deliberate.

COUNT 2
(Patent Infringement by 3M of '733 Patent)

19. Paragraphs 1 through 18 are realleged as though fully set forth herein.

20. 3M, without the permission of Kerr, has been and still is manufacturing, selling and offering for sale, within the United States, a device for curing materials with light radiation that infringes on the '733 patent. 3M's actions constitute both direct and indirect infringement of the '733 patent.

21. Upon information and belief, Dentsply has no reasonable basis to continue

infringement of the '733 patent, and such continued infringement is willful.

COUNT 3
(Patent Infringement by Dentsply of '251 Patent)

22. Paragraphs 1 through 21 are realleged as though fully set forth herein.

23. Dentsply, without the permission of Kerr, has been and still is manufacturing, selling and offering for sale, within the United States, a device for curing materials with light radiation that infringes on the '251 patent. Dentsply's actions constitute both direct and indirect infringement of the '251 patent.

24. Dentsply had actual notice of the '251 patent, and Dentsply's continued infringement of the '251 patent has been and continues to be willful and deliberate.

COUNT 4
(Patent Infringement by Dentsply of '733 Patent)

25. Paragraphs 1 through 24 are realleged as though fully set forth herein.

26. Dentsply, without the permission of Kerr, has been and still is manufacturing, selling and offering for sale, within the United States, a device for curing materials with light radiation that infringes on the '733 patent. Dentsply's actions constitute both direct and indirect infringement of the '733 patent.

27. Upon information and belief, Dentsply has no reasonable basis to continue infringement of the '733 patent, and such continued infringement is willful.

WHEREFORE, Kerr prays that:

1. 3M be adjudged and decreed to have infringed the '251 and '733 patents;
2. Dentsply be adjudged and decreed to have infringed the '251 and '733 patents;
3. A permanent injunction be issued restraining and enjoining 3M, its officers, agents, attorney and employees, and those acting in privity or concert with it, from making using, selling, offering for sale or importing the infringing devices or devices and devices that are no

more than colorable variants thereof;

4. A permanent injunction be issued restraining and enjoining Dentsply, its officers, agents, attorney and employees, and those acting in privity or concert with it, from making using, selling, offering for sale or importing the infringing devices or devices and devices that are no more than colorable variants thereof;

5. 3M be ordered to pay damages adequate to compensate Kerr for 3M's infringement of the patents;

6. Dentsply be ordered to pay damages adequate to compensate Kerr for Dentsply's infringement of the patents;

7. This action be decreed an "exceptional case" within the meaning of 35 U.S.C. § 285 due to 3M's conduct and reasonable attorney fees and costs be awarded to Kerr;

8. This action be decreed an "exceptional case" within the meaning of 35 U.S.C. § 285 due to Dentsply's conduct and reasonable attorney fees and costs be awarded to Kerr; and

9. Kerr be granted such other and further relief as may be proper under the circumstances.

Dated this 3rd day of August, 2006.

MICHAEL BEST & FRIEDRICH LLP

By: 

David L. De Bruin, SBN 1013776
Richard H. Marschall, SBN 1035851
Charles J. Crueger, SBN 1029825
100 East Wisconsin Avenue
Suite 3300
Milwaukee, WI 53202-4108

Attorneys for Plaintiff
Kerr Corporation



US006692251B1

(12) **United States Patent**
Logan et al.

(10) **Patent No.:** **US 6,692,251 B1**
(45) **Date of Patent:** ***Feb. 17, 2004**

(54) **APPARATUS AND METHOD FOR CURING MATERIALS WITH LIGHT RADIATION**

EP 0 320 080 8/1993
EP 0 672 435 9/1995

(List continued on next page.)

(75) Inventors: **Joseph N. Logan**, Trumbull, CT (US);
Raymond L. Knox, Bethel, CT (US)

OTHER PUBLICATIONS

(73) Assignee: **Kerr Corporation**, Orange, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 208 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **09/632,260**

(22) Filed: **Aug. 4, 2000**

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/009,205, filed on Jan. 20, 1998, now Pat. No. 6,200,134.

(51) Int. Cl.⁷ **A61C 3/00**

(52) U.S. Cl. **433/29; 362/800**

(58) Field of Search 433/29, 215; 606/1, 606/13, 16; 607/80; 362/800

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,638,013 A	1/1972	Keller	240/41.15
3,712,984 A	1/1973	Lienhard	
3,733,481 A	5/1973	Kuyt	
3,868,513 A	2/1975	Gonser	250/504
3,970,856 A	7/1976	Mahaffey et al.	250/493
4,048,490 A	9/1977	Troue	240/41.35

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

DE	42 11 233	1/1992
EP	0116405	8/1984
EP	0 266 038	10/1991
EP	0 568 666	11/1992

Schlager, Kenneth J., Ignatius, Ronald W., *An LED-Array Light Source for Medical Therapy*, SPIE vol. 1892 Medical Lasers and Systems II (1993) p. 26-35.

Tarle, Z. et al., *The Effect of the Photopolymerization Method on the Quality of Composite Resin Samples*, J. of Oral Rehab. 25: 436-442, 1998.

Burgess, John O. et al., *An Evaluation of Four Light-Curing Units Comparing Soft and Hard Curing*, Pract. Periodont Aesthet. Dent. 11(1), 125-132, 1999.

Kanca, III, John and Suh, Byoung I., *Pulse Activation: Reducing Resin-Based Composite Contraction Stresses at the Enamel Cavosurface Margins*, Am. J. of Dentistry, 12(3), 107-112, 1999.

(List continued on next page.)

Primary Examiner—Ralph A. Lewis

(74) *Attorney, Agent, or Firm*—Wood, Herron & Evans, LLP

(57) **ABSTRACT**

An instrument and method for curing light-curable compounds in the mouth of a patient, the instrument comprising a housing and a plurality of solid state, light-emitting elements on a substrate supported by the housing. The elements form a collective array on the substrate operable for collectively emitting light having wavelengths within a narrow band of wavelengths.

An optical focusing device is positioned to intercept the light emitted by the array of elements and includes a non-imaging optical device which is operable for collimating the light from the array into a beam to be directed onto a compound for curing the compound. A disposable sleeve covers the housing and array and may incorporate the optical focusing device. The sleeve is removed and discarded after use to eliminate the need to autoclave the instrument.

42 Claims, 3 Drawing Sheets

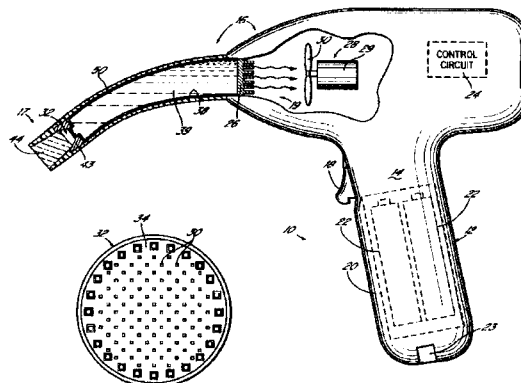


EXHIBIT A

US 6,692,251 B1

Page 2

U.S. PATENT DOCUMENTS

4,114,274 A 9/1978 Jones
 4,114,946 A 9/1978 Hoffmeister et al.
 4,184,196 A 1/1980 Moret et al. 433/29
 4,185,891 A 1/1980 Kaestner 350/167
 4,233,649 A 1/1980 Scheer et al.
 4,186,748 A 2/1980 Schlager 128/736
 4,209,907 A 7/1980 Tsukada et al.
 4,230,453 A 10/1980 Reimers 433/29
 4,280,273 A * 7/1981 Vincent
 4,298,806 A 11/1981 Herold 250/504
 4,337,759 A 7/1982 Popovich et al. 126/438
 4,385,344 A 5/1983 Gonser 362/32
 4,391,588 A 7/1983 Matsui
 4,398,885 A 8/1983 Loge et al. 433/126
 4,450,139 A 5/1984 Bussiere et al. 422/186.3
 4,610,630 A 9/1986 Betush
 4,666,406 A 5/1987 Kanca, III 433/229
 4,729,076 A 3/1988 Masami et al. 362/235
 4,810,194 A 3/1989 Snedden 433/91
 4,826,431 A 5/1989 Fujimura et al. 433/29
 4,846,546 A 7/1989 Cuda 350/96.24
 4,888,489 A 12/1989 Bryan 250/504
 4,935,665 A 6/1990 Murata 313/500
 4,936,808 A 6/1990 Lee 445/24
 4,963,798 A 10/1990 McDermott 315/312
 4,999,310 A 3/1991 Kim 437/51
 5,003,434 A 3/1991 Gonser et al. 362/32
 5,029,957 A 7/1991 Hood 350/96.2
 5,115,761 A 5/1992 Hood 118/641
 5,147,204 A 9/1992 Patten et al. 433/229
 5,150,016 A 9/1992 Sawase et al. 315/294
 5,161,879 A 11/1992 McDermott 362/206
 5,162,696 A 11/1992 Goodrich 313/511
 5,201,655 A 4/1993 Friedman 433/29
 5,233,283 A 8/1993 Kennedy 320/13
 5,242,602 A 9/1993 Richardson et al. 210/745
 5,265,792 A 11/1993 Harrah et al. 228/6.2
 5,278,629 A 1/1994 Schlager et al. 356/313
 5,283,425 A 2/1994 Imamura 250/208.1
 5,290,169 A 3/1994 Friedman et al. 433/29
 5,312,249 A 5/1994 Kennedy
 5,316,473 A 5/1994 Hare 433/29
 5,373,114 A 12/1994 Kondo et al. 174/268
 5,420,768 A 5/1995 Kennedy 362/119
 5,471,129 A 11/1995 Mann 320/21
 5,521,392 A 5/1996 Kennedy et al. 250/492.1
 5,535,230 A 7/1996 Abe 372/43
 5,617,492 A 4/1997 Beach et al. 385/33
 5,634,711 A 6/1997 Kennedy et al. 362/119
 5,660,461 A 8/1997 Ignatius et al. 362/241
 5,664,042 A 9/1997 Kennedy 385/136
 5,698,866 A 12/1997 Doiron et al. 257/99
 5,707,139 A 1/1998 Haitz 362/231
 5,711,665 A 1/1998 Adam et al. 433/9
 5,747,363 A 5/1998 Wei et al. 438/5
 6,008,264 A 12/1999 Ostler et al. 522/4
 6,102,696 A * 8/2000 Osterwalder et al. 433/29
 6,200,134 B1 * 3/2001 Kovac et al. 433/29
 6,331,111 B1 12/2001 Cao
 6,379,149 B1 4/2002 Franetzki
 6,419,483 B1 7/2002 Adam et al.
 6,439,888 B1 8/2002 Boutoussov et al.
 6,468,077 B1 10/2002 Melikechi et al.

FOREIGN PATENT DOCUMENTS

EP 0 755 662 7/1996
 EP 0 736 307 10/1996
 EP 0 780 101 6/1997
 EP 0 780 103 6/1997

EP 0 879582 11/1998
 EP 0 880 945 12/1998
 EP 0 884 025 12/1998
 EP 0 885 025 12/1998
 EP 0 998 880 5/2000
 EP 1 031 326 8/2000
 EP 1 090 607 4/2001
 EP 1 090 608 4/2001
 EP 1 093 765 4/2001
 EP 1 112 721 7/2001
 EP 1 138 276 10/2001
 EP 1 138 349 10/2001
 EP 0 830 851 5/2002
 EP 0 830 852 5/2002
 EP 1 228 738 8/2002
 EP 0 740 567 11/2002
 GB 2 212 010 A 7/1989
 JP 6-30275 2/1994
 JP 8-141001 6/1996
 JP 9-10238 1/1997
 JP 8-194786 2/1997
 JP 410033573 2/1998
 WO 83/01311 4/1983
 WO 84/04463 11/1984
 WO 92/02275 2/1992
 WO 93/09847 5/1993
 WO 93/21842 11/1993
 WO 95/19810 7/1995
 WO 95/26217 10/1995
 WO 97/37722 10/1997
 WO 97/46279 12/1997
 WO 97/46280 12/1997
 WO 98/03131 1/1998
 WO 98/04317 2/1998
 WO 99/11324 3/1999
 WO 99/20346 4/1999
 WO 00/01464 1/2000
 WO 00/02491 1/2000
 WO 00/13608 3/2000
 WO 00/15296 3/2000
 WO 00/41726 7/2000
 WO 00/41767 7/2000
 WO 00/41768 7/2000
 WO 00/43067 7/2000
 WO 00/43068 7/2000
 WO 00/45733 8/2000
 WO 00/67660 11/2000
 WO 00/676048 11/2000
 WO 01/03770 1/2001
 WO 00/14012 3/2001
 WO 01/24724 4/2001
 WO 01/54770 8/2001
 WO 01/60280 8/2001
 WO 01/64129 9/2001
 WO 01/68035 9/2001
 WO 01/69691 9/2001
 WO 02/06723 1/2002
 WO 02/09610 2/2002
 WO 02/32505 4/2002
 WO 02/33312 4/2002
 WO 02/49721 6/2002

OTHER PUBLICATIONS

Swift Jr., Edward J. et al., Ed., *Contemporary Photocuring Issues, Part II*, J. Esthetic Dentistry, 12 (1), 50-57, 2000.

Mayes, Joe II., *Curing Lights: An Overview*, Unknown, p. 15-17.

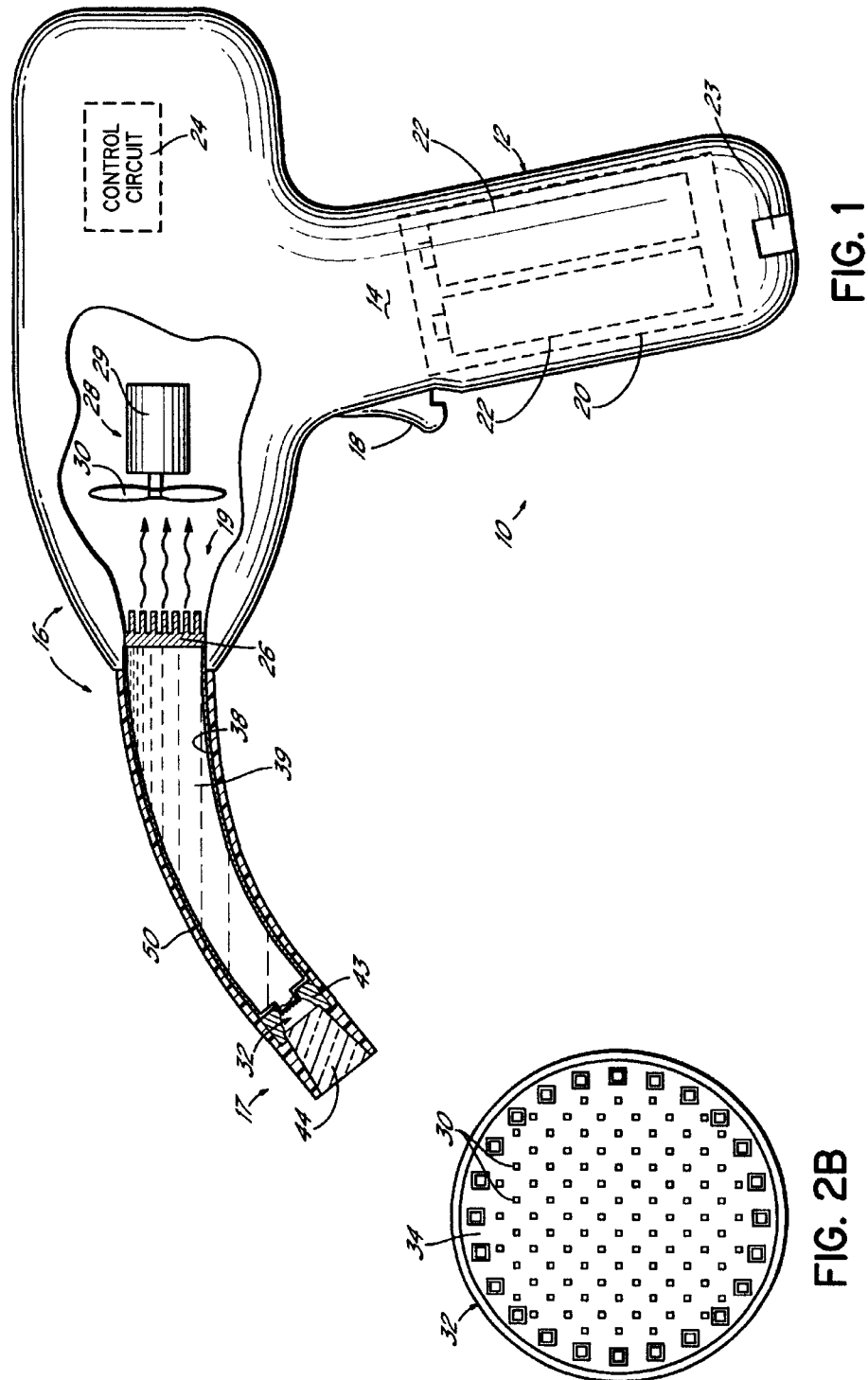
TIR Technologies, Inc., *Miniaturized TIR lenses for Light Emitting Diodes*, TIR Technical Publication, pp. 1-14.

US 6,692,251 B1

Page 3

- Uno, Shigeru and Asmussen, Erik, *Marginal Adaptation of a Restorative Resin Polymerized at Reduced Rate*, Scand J. Dent. Res. 1991; 99: 440-4.
- Davidson-Kaban, Saliha S. et al., *The Effect of Curing Light Variations on Bulk Curing and Wall-to-Wall Quality of Two Types and Various Shades of Resin Composites*, Dent. Mater. 13: 344-352, Nov. 1997.
- Mehl, A. et al., *Physical Properties and Gap Formation of Light-Cured Composites With and Without 'Softstart-Polymerization'*, J. of Dentistry, 25, 321-330, 1997.
- Koran, Peter and Kurschner, Ralf, *Effect of Sequential versus Continuous Irradiation of a Light-Cured Resin Composite on Shrinkage, Viscosity, Adhesion, and Degree of Polymerization*, Am. J. of Dentistry, 11, No. 1, 17-22, 1998.
- Feltzer, A. J. et al., *Influence of Light Intensity on Polymerization Shrinkage and Integrity of Restoration-Cavity Interface*, Eur. J. Oral Sciences, 103: 322-326, 1995.
- Kato, Hiromasa, *Relationship Between the Velocity of Polymerization and Adaptation to Dentin Cavity Wall of Light-Cured Composite*, Dental Materials J. 6(1): 32-37, 1987.
- Sakaguchi, Ronald L. and Berge, Hong Xu, *Reduced Light Energy Density Decreases Post-Gel Contraction While Maintaining Degree of Conversion in Composites*, J. of Dentistry, 26, 695-700, 1998.
- Eibofner et al., *Lighting Fixture for a Medical or Dental Handpiece*, US2001/0007739, U.S. Patent Application Publication, published Jul. 12, 2001.
- Gemunder et al., *Photo Curing Light System Having Modulated Light Intensity Control*, US2002/0014864, U.S. Patent Application Publication, published Feb. 7, 2002.
- Hooker et al., *Optical Waveguide Concentrator and Illuminating Device*, US2002/0051367, U.S. Patent Application Publication, published May 2, 2002.

* cited by examiner



U.S. Patent

Feb. 17, 2004

Sheet 2 of 3

US 6,692,251 B1

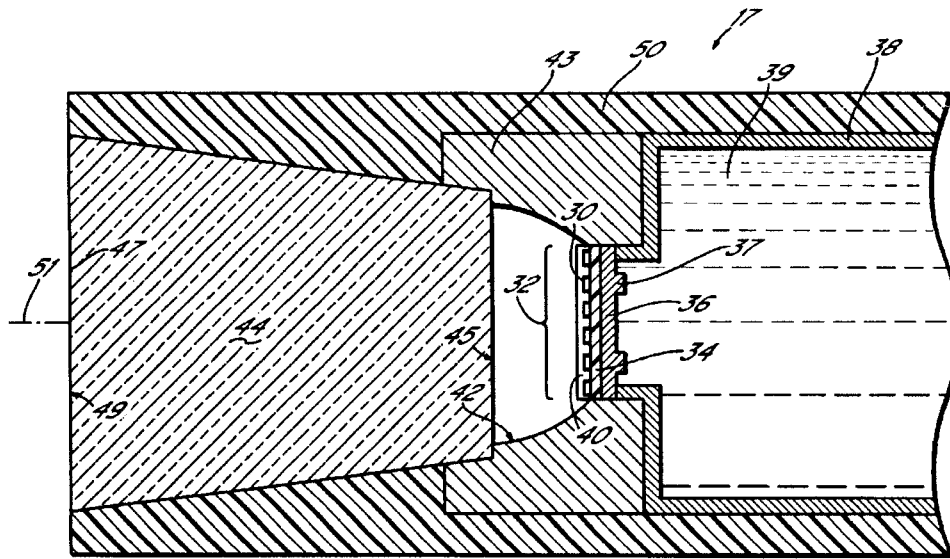


FIG. 2

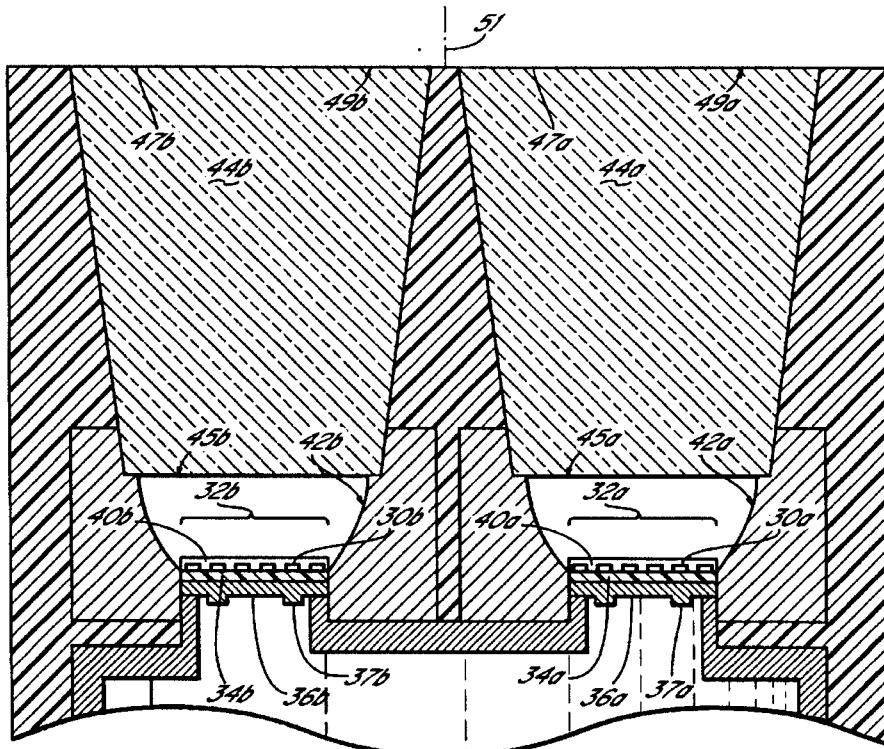
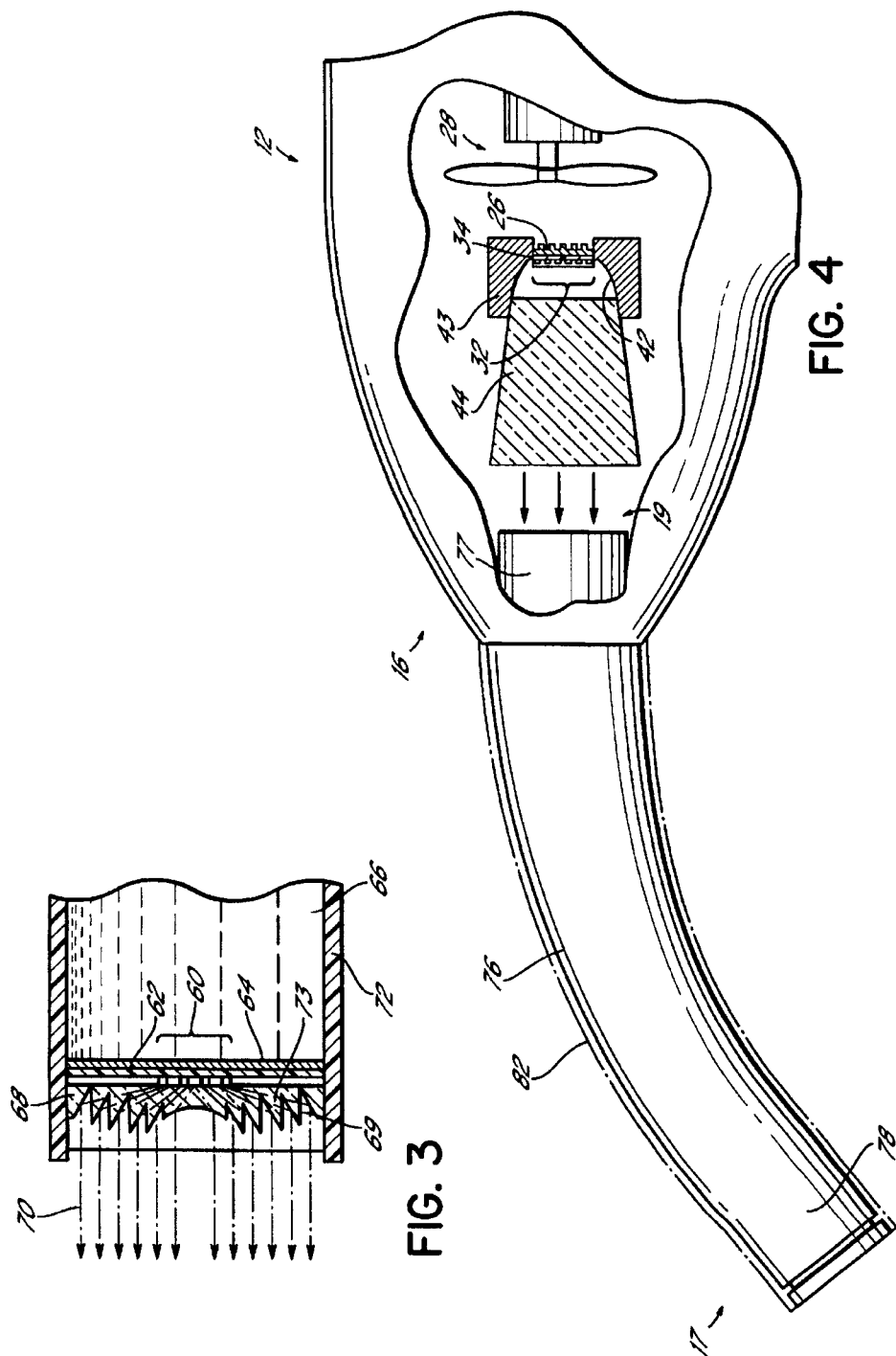


FIG. 2A



US 6,692,251 B1

1

APPARATUS AND METHOD FOR CURING MATERIALS WITH LIGHT RADIATION

RELATED APPLICATIONS

This application is a continuation-in-part of U.S. Ser. No. 09/009,205, entitled "Apparatus and Method for Curing Materials with Radiation" and filed on Jan. 20, 1998 now U.S. Pat. No. 6,200,134 B1, which application is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

This application is related to the curing of materials with radiation and, more specifically, to curing dental coating and filling compounds with light.

BACKGROUND OF THE INVENTION

Curable adhesive compounds and bonding or filling compounds are widely used for structurally connecting object surfaces together or for filling gaps, openings and cavities in an object surface. Such curable compounds are generally manipulated and positioned on the object surface in a semi-solid state and are then hardened or cured in position to a more solid and permanent state. The curing or hardening of applicable compounds is generally a chemical process which is promoted and driven by one or more curing conditions or factors. For example, the curing process may be driven by exposure of the semi-solid compound and components thereof to air or by exposure of such a compound and its components to an energy source, such as a heat source.

Other curable adhesive and filling compounds are cured by exposure to radiated energy, such as visible and non-visible light energy. Such compounds, referred to as light-curable compounds, are manipulated in a semi-solid form into an area or onto a work surface. Light radiation, preferably in the form of a light beam at a specific wavelength or band of wavelengths, is then directed onto the compound. The compound includes light-sensitive chemical components therein which, when exposed to the light at the specific wavelength, promote the curing or hardening of the compound in the desired position on the work surface to bond, fill, or coat the surface.

As an example, light-curable filling and adhesive compounds are widely used in dental procedures. Dentists use light-curable dental compounds for coating and sealing tooth surfaces, filling caries and other cavities in the tooth surface, and securing crowns and various other dental structures to a tooth surface. Conventionally, dental compounds are cured by exposure to light in the blue range of the spectrum. Once cured, the dental compound reduces further tooth decay, bonds the dental structure, and/or provides additional structure to a tooth. Therefore, it is important that the compounds are completely cured.

More specifically, for curing light-curable dental compounds, visible blue light, and particularly a blue light beam from a hand-held curing light device, is directed onto a tooth surface containing the desired compound layer. The blue light penetrates into the compound layer on the tooth surface for complete curing. The duration of the exposure to blue light for proper curing of the compound layer is dictated by the type of compound and the thickness of the compound layer, as well as the power level and characteristics of the blue light from the curing light device. For example, a thin tooth surface coating or veneer will require less radiated light power, while thicker, deeper fillings for caries and other

2

cavities will require a greater amount of radiated power directed onto the tooth surface for proper curing.

While light-curable compounds have shown very beneficial results in the dental field, existing techniques and dental curing light devices utilized to deliver the light to the tooth surface have various drawbacks. For example, existing dental curing devices require specific filtering mechanisms. Filtering must be done for several reasons. First, it is known that certain wavelengths of blue light are harmful to human tissue. While attempts are made to direct the light beam only on to the tooth surface, a certain amount of oral tissue exposure to the light is inevitable. Therefore, harmful wavelengths must be filtered. Additionally, light-curable compounds are usually sensitive to light having a somewhat specific wavelength, such as a specific blue light wavelength with currently available dental compounds. Therefore, a dental curing light filtering device is tuned to emit light at the proper wavelengths for both patient safety and proper curing.

Many existing conventional dental curing lights use broad spectrum lamp elements, such as halogen bulbs. As a result, dental curing lights must utilize special and complicated filtering devices or filters which receive the broad spectrum light from the lamp element, and then filter the light to provide only the light at the desirable wavelengths. Available lamp elements deliver a wide spectrum of radiation, including visible light, UV light, and infra-red light. Therefore, prior art curing techniques and light devices have generally been very inefficient, because a large amount of the radiated light power is lost simply due to filtering of a significant part of the light spectrum. For example, the input power to a conventional halogen bulb may typically be around 80 Watts, whereas the output power from the dental light device of light at the desired blue wavelength, for example 400–500 nanometers, is typically less than one-half (0.5) Watt.

Additionally, the efficiency of the prior art dental curing lights is further degraded by power losses due to the angle of incidence of the radiated light upon the filtering element. For example, many prior art curing lights utilize reflective filters which reflect only the light at the desirable wavelengths, such as blue light, onto the tooth surface and dental compound. Light at the undesirable wavelengths is passed through the filter to a light absorbing component where it is dissipated. If the angle of incidence of the light from the halogen bulb varies significantly from the desired angle of incidence for the filtering element surface (e.g., 45°), then a reduced amount of the desirable light is reflected onto the tooth surface. This further decreases the amount of desirable light power which is available for curing the dental compound. Conversely, a higher amount of light at undesirable wavelengths may also be reflected onto the tooth surface, rather than being transmitted through the filtering element to be dissipated.

Still another drawback with prior art curing lights is that they generate significant amounts of heat and therefore require complicated cooling systems to operate within the proper temperature range. The significant amount of light energy at the undesirable wavelengths, which is generated by the halogen bulb, must be filtered or otherwise captured. The captured or filtered energy is then dissipated in the form of heat. Therefore, power absorbing and heat dissipating elements are required within conventional curing light devices.

Thermal shields are often utilized in conjunction with reflective filters to absorb and dissipate the unreflected,

US 6,692,251 B1

3

unused light energy in the form of heat. The high power output required for the halogen bulb to produce the desired light power level for curing, creates a significantly high thermal load on the shields. The shields must then be cooled. Generally, fan elements are used in the dental light device to provide convective cooling to the shields. The additional cooling elements increase the size of the light device and complicate its design. As will be appreciated, it is desirable to keep the light device as small and maneuverable as possible, since it is hand-held and used in a patient's mouth.

Additionally, a thermal load is also placed on the reflective filter element, which must then also be cooled, such as by heat sinks and fans. The absorption devices and heat dissipating systems not only complicate the operation and design of the light device, but also make it more expensive to produce, and more subject to operational failure.

Another drawback of prior art dental curing light devices is the limited operational life of the lamp element, such as a halogen bulb. The bulbs frequently burn out and must be replaced. Furthermore, the heat generated inside the light device, which is usually enclosed, shortens the effective operational lifespan of the bulb.

Attempts have been made in the prior art to address some of these drawbacks. For example, Japanese Patent Applications No. 6-30275, 6-285508, 7-163863, and 8-194786; U.S. Pat. Nos. 5,420,768 and 5,634,711; and U.K. patent application No. GB 2,329,756, all disclose various devices using packaged, conventional light-emitting diodes or LEDs, to provide a curing light source with light in the desirable blue range. While specific blue light is provided by the LEDs without significant filtering, various of these devices require complicated internal designs for focusing of the curing light, or require specific electronic control of the LEDs. Furthermore, large numbers of conventional LEDs are necessary. As illustrated in the Figures of those applications, the solid state LED elements are spread out over a circuit board or other support structure and require a somewhat large housing to contain all of the conventional LEDs necessary for generating the intensity of light which is required for practical curing uses. Therefore, it has been difficult to provide a suitable curing light using conventional LEDs, which will generate sufficient curing power in a small and complete design.

Using traditional packaged LEDs, as disclosed in the above-cited art, has specifically presented difficulties associated with generating sufficient curing power within a reasonably sized device which may be adequately cooled. Further complications with such devices have resulted from attempts to concentrate the light from the large grouping of traditional LEDs into a small area and at a sufficient power density so as to be useful for curing. Such difficulties in providing a suitable curing light device utilizing the existing traditional packaged LED technology is highlighted by the lack of a well-received and widely-utilized dental curing light on the market which utilizes such technology.

Alternatively, the devices and technology disclosed in U.S. patent application Ser. No. 09/009,205, noted above, have provided a curing device with solid state, light-emitting components which generate sufficient curing power densities in a reasonably-sized device that may be properly cooled. Further efforts by the inventors of the present application are continuing to improve the existing technology disclosed in that earlier application and to provide the desirable curing power density, size and thermal characteristics required for a successful commercial curing device.

Still another drawback associated with prior art curing lights is their inefficiency in transmitting the light to the

4

work surface, such as a tooth surface, once the light has been generated by the element or bulb. The light is generated within the main housing of the curing light, and must be transmitted to an output end of the housing. Existing dental curing lights utilize elongated light guides to deliver light from the light generating elements inside the housing to the tooth.

Light guides are usually comprised of a large number of optical fibers fused together into an elongated guide. The air/glass interfaces between the generating elements and the input end of the light guide and the output end of the light guide and the inside of the mouth are inefficient and may produce approximately a 10% loss in power per interface. Furthermore, prior art devices may utilize a converging lens to focus light into the input end of the light guide. This provides another lossy interface encountered by the light. Such inefficiencies further increase the cure time that is necessary, and/or create the need for higher power (and associated heat) to provide the necessary curing light intensity.

Another concern with dental curing lights is that such lights are medical/dental instruments, and a portion of the instrument is introduced into a cavity of the body, i.e. the mouth. Since the same curing light will be utilized with different patients, cross-contamination between patients must be avoided. Accordingly, sterilization of the curing light, or a portion thereof, has been necessary with conventional devices. Sterilization, often referred to as autoclaving, requires additional equipment which must be purchased and maintained by the dentist or other physician. Sterilization also introduces an extra step in between curing procedures. Furthermore, the high heat required for sterilization may, over time, damage components of the curing light. Accordingly, conventional curing lights must be designed to withstand sterilization and the high temperatures associated therewith of to otherwise address the sterilization issue.

Accordingly, it is an objective of the present invention to provide a simple, durable curing light device for hardening or curing light-curable compounds. Particularly, it is an objective to provide such a curing light device for curing dental compounds used for dental fillings and coatings.

It is another objective to provide a curing light utilizing solid state light elements.

It is another objective to provide a curing light which has a compact and simple design and which is capable of providing a light power density that is useful for practical curing applications.

It is still another objective of the present invention to cure compounds with curing lights utilizing less power and having greater efficiency to reduce the amount of heat energy generated by the device and thus reduce the heat energy which must be dissipated. Furthermore, it is desirable to provide more efficient cooling of the light-generating devices.

It is still another objective of the invention to eliminate the necessity of reflective filters and other filter elements within a light device for curing light-curable compounds.

It is still another objective to address the need for sterility within a curing light.

It is still a further objective to provide a blue light device which operates within a small space and is easily manipulated within the mouth of a dental patient.

These objectives and various other objectives will become more readily apparent from the Description of the Invention below.

US 6,692,251 B1

5

SUMMARY OF THE INVENTION

An instrument and method for curing light-curable compounds, such as dental compounds in the mouth of a patient, comprises a housing which supports a plurality of solid state, light-emitting elements. The elements are preferably light-emitting dies formed of a semiconductor material. The elements are mounted on a substrate supported by the housing to form a collective array which is operable for collectively emitting light having a wavelength within a narrow band of wavelengths. In one embodiment of the invention, the narrow band of wavelengths includes that of the blue wavelength. However, other wavelengths might also be utilized, depending upon the light sensitivity of the curable compound utilized.

One suitable housing for the invention includes a gun-shaped housing which has a handle portion and a barrel portion. The handle portion is held by an operator and the barrel portion is directed toward a work surface, such as a tooth. A portable power supply may be utilized within the housing such that the instrument is a hand-held instrument which is completely portable. In one embodiment of the invention, the array of light-emitting elements is positioned on the distal end of the barrel portion of the housing which is placed within the mouth of a patient so that the light is delivered directly to a work surface, such as a tooth. In an alternative embodiment, the array of elements may be positioned in the housing such that the generated light must be transmitted to the distal end, such as by an optical fiber light guide.

In accordance With one aspect of the present invention, an optical focusing device is positioned to intercept the light emitted by the array of elements. The optical focusing device is a non-imaging optical device which is operable for collimating the light from the array into a beam to be directed on to a compound for curing the compound. The non-imaging device efficiently collimates and transmits the light from the array to a work surface without inefficiencies associated with imaging lenses in the prior art. A reflective element may be positioned between the array and the optical focusing device for further efficiently directing light from the array into the optical focusing device to be collimated and delivered to a work surface.

In accordance with another aspect of the present invention, the array of dies is arranged on a substrate in a density which is operable for emitting a power density of light in the range of 200-1400 mW/cm². Such a density provides a desirable curing power to the work surface for a suitable cure. For cooling such an array and the substrate on which the elements are mounted, the present invention utilizes conductive cooling wherein a heat tube containing a heat-conductive liquid is thermally coupled to the substrate for conductively transferring heat generated by the array of elements away from the substrate. In one embodiment of the invention, the heat sink is thermally coupled to the substrate and the heat tube is then thermally coupled to the heat sink. In that way, heat is conductively transferred away from the substrate and elements. A heat exchanger is coupled to the other end of the heat tube for convectively transferring heat to the air, such as with the utilization of a fan.

In another aspect of the present invention, a sleeve is utilized over a portion of the housing during the curing process. After each curing process, the sleeve may be removed and discarded or autoclaved, thus eliminating the requirement of autoclaving the entire curing instrument after each use and prior to the next use. To that end, the sleeve could be completely disposable to be discarded after one

6

use. In one embodiment of the invention, the non-imaging optical device, such as a non-imaging lens, and a reflective element are coupled to an end of the sleeve. When the sleeve is positioned over a portion of the housing, the reflective element and lens are aligned coaxially with the array collimating light from the array. In a disposable embodiment of the sleeve, both the non-imaging lens and reflective element are disposable and are discarded with the sleeve after each use.

The array, which comprises a plurality of dies positioned on a flat substrate, generally emits light within a range of 0-180°. When the array is located at the distal end of the housing, the non-imaging lens and reflective element are capable of capturing the light within the 180° range and effectively and efficiently collimating the light into a beam directed to the work surface. When the array is positioned further within the housing, away from the distal end of the housing, and away from the work surface, the non-imaging lens is operable for collimating light within the 180° range into a beam which does not diverge significantly from an acceptance angle of an optical fiber light guide. In that way, light is efficiently directed through the light guide and housing to the distal end of the housing whereupon it is emitted onto a work surface, such as a tooth. Preferably, the array is mounted onto the distal end of the housing for directly delivering light to the work surface. In that way, an optical fiber light guide, which has multiple lossy air/glass interfaces, may be eliminated for efficient transmission of light.

One embodiment of the invention utilizes a single non-imaging optical focusing device for the array of elements. Alternatively, the elements might range in sub-groups on the array and multiple, non-imaging optical devices may be utilized.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with a general description of the invention given below, serve to explain the principles of the invention.

FIG. 1 is a side view in partial cross-section of one embodiment of a curing light device in accordance with the principles of the invention.

FIG. 2 is a side view, in partial cross-section, of a portion of the embodiment of the invention illustrated in FIG. 1.

FIG. 2A is a side view, in partial cross-section, of a portion of another embodiment of the invention.

FIG. 2B is a plane view of an array of dies in accordance with an embodiment of the present invention.

FIG. 3 is a side view, in partial cross-section, of a portion of another embodiment of the invention.

FIG. 4 is a side view, in partial cross-section, of a portion of another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 illustrates one embodiment of a curing light device or curing light for curing light-curable compounds such as dental compounds in accordance with the aspects of the present invention. In FIG. 1, device 10 includes a housing 12 which is to be manipulated for curing. Housing 12 is generally gun-shaped and includes a handle portion 14 and a barrel portion 16. The operator, such as a dentist, grips housing 12 around the handle portion 14 and directs the

US 6,692,251 B1

7

barrel portion 16 in the direction of the tooth surface (or other work surface) and compound to be cured (not shown). For curing dental filling and coating compounds, the dentist would generally position at least part of the barrel portion in the mouth of a patient with a radiating end 17 of the barrel portion pointing at a particular tooth or teeth. The handle portion 14 includes an operational trigger switch 18 which is operably coupled to a power supply 20 and/or control circuit 24 for selectively operating the device and supplying power to light-emitting elements 32 to generate a curing light beam, as discussed further below. The power supply 20 is shown located in handle portion 14, but might also be located elsewhere in the housing.

In one embodiment of the invention, the power supply is portable and incorporates batteries 22. The batteries could be any suitable type (e.g. lithium batteries), and may be disposable or rechargeable. To that end, housing 12 may include a port 23 for coupling an external charger (not shown) to the power supply 20 to charge rechargeable batteries 22. Alternatively, an external power supply, such as one powered by an AC outlet, may be coupled to power supply 20 to provide the power necessary to operate device 10.

A control circuit 24 is mounted within housing 12 and is operably coupled to the power supply 20, trigger switch 18 and the other components of device 10, such as array 32, for operating and controlling the components. Control circuit 24, for example, may include various electrical circuit components mounted on a circuit board and arranged in a way determined by a person of ordinary skill in the art for providing the desired power and control of device 10. For example, the control circuit 24 will usually include conventional control circuits for a curing light device, such as a timer, for timing the operational radiation cycle for the device when the trigger switch is engaged. A microprocessor may also be utilized for such control, rather than discrete components. It will be readily understood that the control circuit may be configured in various different ways to properly operate curing light 10. In one embodiment, the microprocessor control will regulate the lamp voltage to produce a constant output. In other embodiments, the microprocessor control might be utilized to ramp the power up or down in a selected fashion for proper curing.

Barrel portion 16 is appropriately formed and may include an angled distal or radiating end 17 to direct a curing light beam 21 out of the housing and onto a tooth surface or other work surface. It will be understood by a person of ordinary skill in the art that the shape of housing 12 may also vary. Barrel portion 16 is shown as solid in the Figures; however, it might also be vented for heat dissipation purposes. Furthermore, the barrel portion 16 might be separate from the rest of the housing and removably secured to the housing by any suitable method as is known in the art. For example, the barrel portion 16 might be screw-mounted to the housing 12. Still further, the power supply might be positioned in line with the barrel portion to reduce or eliminate the handle portion and thereby streamline the design, such as for a small, pocket curing light. The housing 12 is formed of a suitable light-weight plastic material such as polysulphone.

FIG. 1 illustrates one embodiment of the present invention in which a beam of radiation or light 21 utilized for curing purposes is generated by an array 32 of light-emitting elements positioned proximate the radiating end 17 of the barrel portion 16. Heat generated by the array 32 is transmitted from the radiating end 17, or distal end, back to a proximal end 19 of the barrel portion, where it is further dissipated. In the embodiment of FIG. 1, a heat tube 38 is

8

thermally coupled to the array 32 and conductively transfers heat generated by the array to a heat exchanger 26, which is then convectively cooled. An appropriate fan 28 with motor 29 and blade 30 may be mounted within the housing 12, as shown in FIG. 1 to assist convective cooling.

More specifically, referring to FIG. 2, the illustrated embodiment of the present invention utilizes a plurality of individual light-emitting dies 30 which are mounted to form a collective array 32 on a substrate 34. The dies 30 are small, bare semiconductor junctions and are constructed using a light generating semiconductor material. The dies 30 are preferably not separately or individually packaged or otherwise mounted with individual integral lenses as are conventional light-emitting diodes or LEDs. Conventional LEDs used in the prior art have integral and individual packages, usually including a reflector and an integrally formed individual lens. The dies of the invention might be used with additional components, such as a clear protective coating 40, which is applied over the dies on substrate 34, or other added components. However, the dies as mounted are essentially bare semiconductor junctions, without prepackaged individual and integral reflectors and lenses, as are found in conventional LEDs.

As noted above, the dies 30 are not individually lensed, as are conventional LEDs. However, they might be covered with a clear protective layer or coating 40 of plastic to improve the durability of the array 32.

The substrate 34 is an electrically insulated substrate which has heat conductive properties. In one embodiment of the invention, substrate 34 may be a sapphire substrate or a diamond which has electrically insulative properties, but which also conducts heat away from the die array 32. For the purposes of uniform light generation within a beam having a generally circular cross-section, the dies of array 30 are preferably arranged in a circular pattern. U.S. patent application, Ser. No. 09/009,205, illustrates several circular patterns of dies and light generating elements suitable for an embodiment of the present invention.

The substrate 34 is bonded to a heat sink 36, formed of a suitable thermally conductive material, such as copper. Heat sink 36 is then welded or soldered to one end of a liquid-filled heat tube or pipe 38 for conductively transferring heat generated by the dies 30 away from the heat sink 36, substrate 34 and array 32. A heat conductive liquid 39 contacts the back side of heat sink 36, opposite substrate 34 and array 32 (see FIG. 2), and thermally pulls heat from the sink. Therefore, the die array is effectively conductively cooled using the heat tube 38 and the intermediate elements 34, 36. Heat tube 38, which includes a heat conductive liquid 39 therein, such as saline, is commercially available from Aavid Thermal Technologies.

One particularly unique aspect of the present invention is that the array 32 is conductively cooled to provide adequate heat transfer from the light-generating dies 30. Prior art structures have traditionally relied upon convective cooling in which a heat sink and other heat dissipating devices thermally coupled to the light-generating elements are convectively air cooled, such as by a fan. One particular problem with prior art devices has been the dissipation of heat which is generated by the LEDs or other light-generating elements utilized therein. In the present invention, the heat tube 38 rapidly conductively draws heat away from array 32 and dies 30 for improved cooling characteristics. This allows a sufficient amount of curing light power to be generated for proper curing while maintaining an array which does not overheat. The present

US 6,692,251 B1

9

invention therefore provides improved heat transfer and dissipation capabilities with respect to the prior art.

Referring again to FIG. 1 and the embodiment of the invention which utilizes the array 32 located at the distal, or radiating end 17 of barrel portion 16, the opposite, or proximal, end of the heat tube 38 is thermally coupled to a heat exchanger 36, which is then convectively cooled by fan 28. The heat exchanger, which may be soldered to the heat tube 38, has fins, as shown, over which air is directed. Therefore, the die array 32 is conductively cooled by the heat tube 38 and a liquid therein, and the heat tube is then convectively cooled at the opposite end by air, such as by a fan.

For directing and collimating the beam 21 generated by array 32, the embodiment of the invention illustrated in FIG. 2 utilizes a reflective surface 42, and an optical focusing device 44 to collimate light from the array 32 into a beam to be directed into the mouth of the patient for curing compound therein or to be directed to some other work surface. As shown, the array 32, reflective surface 42 and optical focusing device 44 are all positioned at the distal end of the barrel portion. Thereby, the light is directly radiated onto the work surface and compound. Therefore, the embodiment of FIGS. 1 and 2 eliminates various air-to-object interfaces which tend to be lossy. As such, the present invention more efficiently delivers power from the light generating elements to the work surface. Generally, the radiating or distal end 17 will be positioned in the mouth of the patient to radiate a beam of light directly onto a work surface with a light-curable compound. Prior art devices using light transmitting devices with multiple lossy interfaces often have difficulty in generating sufficient light power densities for curing. The present invention addresses this issue by eliminating various lossy interfaces.

To focus the light from array 32, the curing light device 10 uses a reflective surface or reflector 42 which encircles the array as shown in FIG. 2. In the illustrated embodiment, the reflective surface 42 is formed by an appropriately shaped plastic ring structure 43, which circumferentially surrounds the outer edge of array 32 defined by substrate 34. Reflective surface 42 is generally parabolic in shape and is formed by coating the surface 42 of plastic structure 43 with a reflective coating for the purpose of efficient reflection. A mylar coating, available from 3M, has proven to have suitable properties for that purpose and has an approximately 99% reflective efficiency for the purposes of the present embodiment of the invention illustrated in FIG. 2. As shown in FIG. 2, the plastic ring structure 43 forms the generally parabolic reflective surface 42 around array 32 for directing the light away from the dies 30 and into an input end 45 of the optical focusing device 44.

The optical focusing device, in accordance with one embodiment of the invention, is a non-imaging device. One suitable non-imaging optical focusing device is a non-imaging lens 44 having a generally truncated conical shape, as illustrated in FIG. 2. A non-imaging lens, such as lens 44, receives the light from array 32 at an input end 45 and directs and concentrates the light from array 32 into a focused beam at the output end 47 of the non-imaging lens 44. However, the non-imaging lens does not form an optical image, which is inefficient. A non-imaging optical focusing device as used in the present invention efficiently collimates light so that a desirable light power density is achieved at the work surface, such as a surface of a tooth. The light power density from the array 32 is not reduced by the formation of an image as with traditional optical lenses. One suitable, non-imaging lens is formed of a transparent polycarbonate material. As

10

illustrated, structure 43 is appropriately formed to receive the input end 45 of lens 44 to position the lens in coaxial alignment with the array 32 and surface 42 about axis 51. Each of the lens and surface 42 preferably have generally circular transverse cross sections for efficient transfer of the light along axis 51. One suitable combination of a reflective surface and optical focusing device, which are operably coupled together, is available from Teledyne, of Hawthorne, Calif.

The embodiment of the invention illustrated in FIG. 2 shows a single non-imaging optical focusing device 44 for the array 32 of dies. In accordance with another aspect of the present invention, it is anticipated that multiple non-imaging optical focusing devices might be utilized. For example, referring to FIG. 2A, substrate 34a may include multiple groups of dies, 30a, 30b, which are arranged on the substrate 34a to operate as separate groups of light-generating elements. To that end, a non-imaging optical focusing device 44a may be associated with one group of dies 34a, while another non-imaging optical focusing device 44b may be associated with dies 30b of the other group. Of course, greater numbers of non-imaging optical focusing devices may be utilized for other discrete groups of dies. Generally, however, there will be a substantially smaller number of non-imaging optical focusing devices than there are individual dies. That is, in the embodiments of the invention illustrated in FIGS. 2 and 2A, a single non-imaging optical focusing device will serve a multiple number of individual light-emitting dies. The multiple focusing devices will cooperate to transmit light along axis 51.

In accordance with another aspect of the present invention, the barrel portion 16 of the device 10, particularly the distal or radiating end 17 of the barrel portion, is inserted into the mouth of the patient for curing compound therein. Accordingly, before use with the next patient, it will be appreciated that the device would have to be sterilized. Prior art devices must be completely sterilized, such as by autoclaving, as mentioned above, which further complicates and delays the curing procedure. The present invention provides a unique construction which eliminates the requirement of sterilization of the entire device or of a sterilization process altogether and thereby makes the curing process simpler, quicker, and more cost-effective.

To that end, the invention utilizes a removable sleeve which may be separately autoclaved. Alternatively, as mentioned, the sleeve may be disposable to be discarded after one use. Specifically, in the embodiment of the invention illustrated in FIGS. 1 and 2, the ring structure 43 forming reflective surface 42 and the adjacent non-imaging lens 44 are mounted and secured within a sleeve 50. The sleeve 50 could be made of a suitable disposable plastic, such as PVC, or an autoclavable plastic, and the sleeve is configured for being positioned over at least a section of the barrel portion 16 of the device 10. Preferably, the sleeve is configured to extend over a significant section of the barrel portion 16, and at least over the part of the barrel portion 16 exposed to the mouth of a patient. In the embodiment illustrated in FIG. 2, the sleeve 50 is configured to be positioned over the heat tube 38 and array 32. The sleeve 50 is configured to position the lens 44 and reflective surface coaxially with the array 32. In one embodiment of the invention, once the device has been used for curing, the sleeve 50, ring structure 43, and non-imaging lens 44, may then be removed from the heat tube and away from the array 32 of light-emitting dies. The sleeve, including the lens and reflective structure 43 could then be discarded with the sleeve 50. Alternatively, the sleeve and lens and reflective

US 6,692,251 B1

11

structure could be removed and autoclaved and then placed back in position.

In an alternative embodiment, only the sleeve might be autoclavable or disposable. The lens 44 and ring structure would then remain with the array 32 or could be separately positioned with the array apart from sleeve 50. In such a case, only the sleeve would be discarded or autoclaved.

The device and the component parts, including the heat tube 38, heat sink 36, substrate 34, and dies 32, are not been directly exposed to a patient because they are covered by the sleeve. In the embodiment where the lens and structure 43 are separate from the sleeve, those parts will be isolated as well. Therefore, the isolated or covered components do not have to be sterilized or autoclaved as required with prior art devices and methods. Thereafter, a new or sterilized sleeve, possibly including a new or sterilized reflective structure 43 and lens 44, is inserted onto the heat tube 38 and barrel portion 16 and aligned with the array of dies 32 for the next use. The present invention therefore reduces the possibility of contamination between dental patients and further enhances the curing method by eliminating the sterilization process completely or only requiring that the sleeve be autoclaved. As a result, the curing process is simpler and more efficient. With a disposable sleeve, the process is also more cost effective, as autoclaving equipment does not have to be purchased and operated to sterilize the curing light.

The present invention as illustrated in FIG. 2 also improves upon the prior art by delivering a beam of light from a source close to the work surface (e.g., a tooth). Specifically, the distal or radiating end 17 of the barrel portion 16 is positioned at or proximate a tooth surface containing the curable compound. With the light delivered directly from the array 32 to the surface through only the non-imaging lens 44, numerous lossy air/glass interfaces are eliminated between the die array 32 and the output surface 49 of the device 10. Conventionally, the light generating elements have been positioned away from the work surface and inside the housing such that a fiber optic light guide was necessary to transmit the light to the work surface. Furthermore, with such light guides, it is often necessary to use a converging optical lens before the light guide so that the generated light may be efficiently focused into the input end of the light guide. Light guides and converging lenses present lossy air/glass interfaces to the light beam. It has been estimated that air/glass interfaces may produce light power losses in the range of approximately 10% per interface. By eliminating the interfaces between the dies 30 and the tooth surface, the present invention light transmits light in an efficient, collimated form with less of the power loss at the various interfaces that are required in the prior art. Therefore, the present invention provides efficient transmission of a collimated light beam to the work surface of the tooth and curable compound thereon. With more efficient transfer of light, a smaller number of dies 30 in the array 32 may be used while still providing a sufficient light intensity or light power density at the output surface 49 of the lens. In that way, the invention may provide suitable curing power levels in a generally compact and easily manipulated device. Furthermore, with less loss at the interface, less heat is generated, further improving on the prior art.

In the preferred embodiment of the invention, the dies 30 are positioned in the array 32 with a density sufficient to provide a light power output density at the desired wavelength in the range of approximately 200–1400 mW/cm². In one embodiment of the invention, the dies are generally square in shape, and are 0.010 inches per side. The dies are spot welded to the substrate and specifically to leads (not

12

shown), which are electrically coupled to a control circuit 24 and/or power supply 20. The die substrate is preferably is circular, having a diameter of approximately 0.19 inches (approximately 4.8 millimeters).

A suitable number of dies are positioned on substrate 34 to generate the desired light and power density at the output surface 49 of the non-imaging optical focusing device 44. Generally, in one embodiment of the invention, 30–60 dies are suitable for generating desirable curing light power densities. Of course, a greater or lesser number of dies may be utilized in other embodiments of the invention.

Because of the unique cooling arrangement of the present invention utilizing conductive cooling, the reduction of lossy interfaces and the overall configuration of the embodiment of the invention disclosed herein, the dies may be driven at a sufficient power level to yield the desired light power output or light density, in the range of approximately 200–1400 mW/cm². Generally, the dies may be driven by 12 volts DC in series sets of 3 dies.

For example, one embodiment could be a 34 die lamp which may be operated at 8.13 Watts (8.7 V and 0.935 A). Such a design proved efficient and performed a suitable job of curing. Another embodiment might use 60 die for a higher power output (e.g. a 67% increase in power).

In one embodiment of the invention, series groups of three dies are connected in series to a 12 Volt DC source through a current-limiting resistor. To that end, each die is then driven with approximately 4 volts DC. Furthermore, by utilizing a 12 Volt source, the fan may also be driven by that DC source. It may be readily understood that other arrangements of dies may be utilized, driven by sources having various different power or voltage output levels.

Preferably, the dies 30 are positioned in the array 32 in a sufficient density to provide a curing light which has a suitable light power output for proper curing, but which does not overheat tissues surrounding the work surface, such as a tooth. The inventive lamp will provide less heat to the tissue than a halogen lamp. For example, an embodiment with 34 die as described above yielded a radiometer reading of 200 mW/cm², while a comparable cure with a 52 Watt halogen lamp yielded readings around 600 mW/cm². Because of the much lower radiometer readings, tissue damage should not be as significant an issue with the invention as with a halogen light.

With current dental applications, it is desirable to utilize a die array 32 which generates blue light in a wavelength range of approximately to 470±20 nanometers because current compounds are sensitive to blue light. Current filtered halogen lamps produce light in the 400–500 nanometer range. While such blue light is suitable for current dental applications, the present invention is not limited to only blue light wavelengths for curing purposes. Rather, the present invention may be utilized with compounds that may cure utilizing light at other various wavelengths.

Furthermore, the non-imaging optical focusing device 44 may be sized appropriately depending upon the application. For example, a lens having an 8 millimeter cross-sectional diameter at the output surface 49 may be utilized for small curing applications, whereas a lens having a cross-sectional diameter of 11 millimeters at surface 49 might be utilized for larger curing applications. As may be appreciated, to ensure efficient transfer of curing light to the work surface, it is desirable that a majority, if not all, of the light generated by the dies of array 32 is transmitted into and out of the non-imaging optical focusing device 44. To that end, the reflective surface 32 is shaped and configured in diameter to

US 6,692,251 B1

13

ensure that the light beam is collected and reflected into the input end 45 of the optical focusing device 44. In the illustrated embodiment, the output end 51 of the reflective surface which interfaces with the input end 45 of the optical focusing device is smaller in diameter than the input end 45. In that way, the light reflected by surface 42 is captured by the optical focusing device 44. The non-imaging optical focusing device 44 is not restricted by a focal length, since it is a non-imaging device. In that way, the device 44 captures and collimates the light beam for efficient transmission to a work surface, such as a tooth. Therefore, the present invention is not particularly sensitive to the distance which the output end 49 is maintained from the tooth surface. Of course, it is generally desirable to position the output end 49 as close to the tooth surface as possible for efficient curing.

In accordance with another aspect of the invention, the dies 30 might be evenly arranged on substrate 34 to form a generally circular array, as illustrated in several of the embodiments disclosed in U.S. Pat. No. 6,200,134B1. The dies might also be mounted in various groupings, such as subgroups of four or some other number, and then such subgroups would be mounted on the substrate. That is, subgroups of multiple dies could be individually mounted and electrically coupled together, and subsequently the subgroups could be mounted on the substrate with other subgroups. As such, the invention would not be limited to individual mounting of all of the dies.

FIG. 3 illustrates another embodiment of the invention wherein the die array is also positioned proximate the distal, or radiating end 17 of the barrel portion 16 of the housing. In the alternative embodiment, the structure is somewhat similar to the device 10 illustrated within FIGS. 1, 2, and 2A, with a different construction at the distal or radial end 17, as illustrated in FIG. 3. Specifically, the alternative embodiment utilizes an array of dies 60 mounted on a substrate layer 62. The substrate layer could be sapphire or diamond which has suitable thermally conductive properties for heat dissipation while remaining electrically insulated. Substrate 62 is then bonded to a heat sink 64 which may be made of a suitable material, such as copper. The die array 60 and the assembly including the substrate 62 and heat sink 64 are then welded or soldered onto an end of a liquid-filled heat tube 66, which conductively transfers heat away from the heat sink. In that way, the alternative embodiment of the invention utilizes the advantages provided by the above-discussed embodiment, due to the conductive cooling of the substrate and die array. As illustrated in FIG. 1, the opposite end of the heat tube 66 is coupled to the heat exchanger 26 which is convectively cooled, such as by a fan 28.

To focus light from the die array 60 in an efficient manner into a collimated and focused light beam, the embodiment of the invention shown in FIG. 3 utilizes a total internal reflection, or TIR lens. TIR lenses are known (e.g., U.S. Pat. No. 4,337,759) and are commercially available, such as from TIR Technologies, a division of Teledyne. TIR lenses are more efficient than typical Fresnel lenses, and provide a collimated beam of light generated by the die array 60. The TIR lens structure 68, shown in FIG. 3, utilizes a series of saw-tooth surfaces 69 for collimating light from the array 60 at various different angles into a beam of light 70 focused in a direction generally perpendicular to the plane of the array, as illustrated by reference numeral 70. In that way, light from the array may be efficiently delivered to a curable compound on a work surface. Preferably, the TIR lens is a non-imaging optical focusing device. The lens 68 is appropriately arranged to be generally coaxially aligned with array 60 for efficient light transmission.

14

In accordance with one aspect of the present invention, the TIR lens 68 is formed of a suitable polycarbonate. As discussed above, lens 68 may be incorporated with a disposable sleeve 72 positioned around the heat pipe 66. When an application is complete, the sleeve 72 and TIR lens 69 may be removed and discarded, thus eliminating the need to further sterilize or autoclave the device 10. Alternatively, lens 68 may be separately positioned with respect to sleeve 72 to be separately discarded or to remain with the array 60. The embodiment illustrated in FIG. 3 further provides efficient delivery of light from the die array to a work surface because the die and lens are positioned at the radiating or distal end 17 of the barrel portion to be directly adjacent to the work surface. In that way, various air/glass interfaces are eliminated to reduce power losses associated with such interfaces, as discussed above.

The array 60 of LEDs might be arranged and dimensioned similarly as discussed above with respect to the embodiment illustrated in FIG. 2. The TIR lens 68 will generally have a circular cross-sectional diameter significantly greater than the circular cross-sectional diameter of the array in order for the lens to capture light which is generated by the array at very small angles with respect to the plane of the array 60. In the embodiment illustrated in FIG. 3, a reflector is not utilized between the die array 60 and the lens 68. Therefore, the lens must be sized appropriately to capture low angle light, such as that illustrated by reference line 73.

FIG. 4 illustrates an alternative embodiment of the invention in which the die array is positioned more centrally within the housing and spaced rearwardly from the barrel portion. Specifically, a die assembly, similar to that illustrated in FIG. 2, is mounted in the housing proximate the proximal end 19 of the barrel portion. The substrate 34 is then coupled directly to the heat exchanger 26, which may be convectively cooled, such as by a fan 28. The barrel portion 16, rather than housing a heat tube, houses a light pipe or light guide 76. Such light guides are commercially available and come in a variety of different sizes. Generally, such light pipes are formed of a plurality of optical fibers (for example, approximately 5,000 fibers which are fused into a single light pipe structure). The beam of light transmitted into the input end 77 located at the proximal end 19 of the barrel portion 16, is transmitted through the light pipe and is directed out the transmission end 78 of the pipe at the distal end 17 of the barrel portion 16. The light pipe may maintain uniform diameter from the input end 77 to the output or transmission end 78, or may taper from one diameter to a smaller diameter at the transmission end 78. Preferably, the light pipe is bent to follow the bent barrel portion 16, illustrated in FIG. 4, so that the beam of light is directed downwardly, such as into the mouth of the patient. Alternatively, the light pipe itself may form part of the barrel portion and may be attached to the housing 12, such as by being screwed into the housing.

The non-imaging optical focusing device, such as a non-imaging optical lens 44, is used to focus the light into the light pipe. The input end 77 of the light pipe is dimensioned appropriately so that light is efficiently delivered through the focusing device 44 to the light pipe 76. To that end, the focusing device 44 collimates the light so that it does not diverge beyond the input end 77 of the light pipe.

Generally, light pipes have a defined angle of acceptance at their input end 77, such as 40°. Light directed outside of that acceptance angle is not captured by the light pipe and transferred to the work surface. The reflective surface 42 and non-imaging optical focusing device 44 utilized in the embodiment in FIG. 4 are designed to generate a beam of

US 6,692,251 B1

15

light which does not diverge more the acceptance angle of the light pipe. In that way, energy is efficiently translated from the array which outputs light in generally a 180° angle. Therefore, the present invention utilizes a non-imaging optical focusing device which collimates light from a 180° light output source to a column which does not diverge more than the acceptance angle of the light pipe to which the light is input.

In still a further embodiment of the invention, the die array and the TIR lens structure similar to that shown in FIG. 3 might be utilized within the housing as shown in FIG. 4. To that end, the die array 60, substrate 62, and heat sink 64 are coupled to the appropriate heat exchanger, which is then convectively cooled, such as by a fan. In such an embodiment, as well as in the embodiment illustrated in FIG. 4, device 10 would generally have to be sterilized or autoclaved after each use. However, since the die array and optical focusing devices are positioned inside the handle portion of the housing, they would be protected from the high temperatures associated with such sterilization.

Alternatively, as illustrated in FIG. 4, a disposable sleeve 82 might be utilized with the embodiment to cover the light pipe. The disposable sleeve 82 may be discarded with each use, thus effectively eliminating the required autoclaving step.

While the present invention has been illustrated by the description of the embodiments thereof, and while the embodiments have been described in considerable detail, it is not the intention of the applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details representative apparatus and method, and illustrative examples shown and described. Accordingly, departures may be made from such details without departure from the spirit or scope of applicant's general inventive concept.

What is claimed is:

1. An instrument for curing light-curable compounds which are curable in the mouth of a patient, the instrument comprising:

a housing;

a plurality of solid state, light-emitting die, the die each being a semiconductor junction individually mounted on a substrate to form an array operable for emitting light having wavelengths within a narrow band of wavelengths;

an optically reflective element coupled to surround an outer edge of the substrate and the array of light emitting die for reflecting the light emitted collectively from the die array and directing it toward a compound for curing the compound.

2. The instrument of claim 1 further comprising a non-imaging lens for receiving the light captured by the optically reflective element to further direct it toward a compound.

3. The instrument of claim 2 further comprising a disposable sleeve which is removably mounted with respect to the housing, the optically reflective element and non-imaging lens being coupled to the disposable sleeve.

4. The instrument of claim 1 wherein said substrate is formed of one of diamond and sapphire.

5. The instrument of claim 1 further comprising a heat sink thermally coupled to the substrate for absorbing heat generated by the die.

6. The instrument of claim 1 further comprising a thermally conductive element which is thermally coupled to the

16

substrate for conductively transferring heat generated by the die away from the substrate.

7. The instrument of claim 6 wherein said thermally conductive element comprises a heat tube.

8. The instrument of claim 1 further comprising a heat exchanger which is thermally coupled to the substrate for dissipating heat generated by the die.

9. The instrument of claim 1 further comprising a heat sink thermally coupled to the substrate for absorbing heat generated by the die, and a heat tube thermally coupled to the heat sink for conductively transferring heat generated by the die away from the heat sink and the substrate.

10. The instrument of claim 1 wherein said housing comprises a barrel portion having a distal end configured to be placed in the mouth of a patient, the die array being supported proximate to said distal end for being positioned in the mouth of a patient to cure a compound.

11. The instrument of claim 1 wherein said housing comprises a barrel portion having a proximal end spaced from a distal end of the barrel portion, the distal end being configured to be placed proximate to the mouth of a patient, a light transmitting element being operably coupled with the optically reflective device for transmitting the light through the housing distal end.

12. The instrument of claim 11 wherein said light transmitting device comprises a plurality of fiber optic elements operably coupled together for directing said beam.

13. The instrument of claim 11 wherein said light transmitting device has an acceptance angle, said optically reflective element is operable for generating a beam of light which does not diverge significantly from said acceptance angle.

14. The instrument of claim 13 wherein said light-emitting die emits light in the range of 0°-180° and said optically reflective element is operable for collimating the light into a beam which does not diverge significantly from said acceptance angle.

15. The instrument of claim 1 further comprising a sleeve which is removably mounted with respect to the housing.

16. The instrument of claim 15 wherein said optically reflective element is coupled with the sleeve.

17. The instrument of claim 16 wherein said housing comprises a barrel portion having a distal end which is configured to be placed in the mouth of a patient, the sleeve having the optically reflective element coupled at one end thereof and configured for being attached to the barrel portion such that the optically reflective element is positioned proximate said distal end to deliver a light beam into the mouth of the patient.

18. The instrument of claim 15 wherein said sleeve is made of a disposable material to be discarded after one use.

19. The instrument of claim 15 wherein said sleeve is made of an autoclavable material to be sterilized after a use.

20. The instrument of claim 1 further comprising a portable power supply positioned within said housing for portable operation of the instrument.

21. The instrument of claim 1 wherein said instrument is operable for emitting a power density of light in the range of 200 to 1400 mW/cm².

22. The instrument of claim 1 further comprising a plurality of optically reflective elements positioned to capture the light emitted by the array of die.

23. The instrument of claim 22 wherein there are a substantially smaller number of optically reflective elements than light-emitting die, such that each optically reflective element collimates the light from multiple light-emitting die.

24. The instrument of claim 1 further comprising a collimating total internal reflection (TIR) lens for receiving

US 6,692,251 B1

17

the light captured by the optically reflective element to further direct it toward a compound.

25. A method for curing light-curable compounds, the method comprising:

generating light having wavelengths within a narrow band of wavelengths using a plurality of solid state, light-emitting die which each includes a semiconductor junction individually mounted on a substrate to form an array, operable for emitting the light;

capturing the light emitted by the die array with an optically reflective element coupled to surround an outer edge of the substrate and the array of light emitting die for reflecting the light emitted collectively from the die array and directing it toward a compound for curing the compound.

26. The method of claim 25 further comprising thermally coupling a heat sink to the substrate for absorbing heat generated by the die array.

27. The method of claim 25 further comprising coupling to the substrate a thermally conductive element and conductively transferring heat generated by the die away from the substrate.

28. The method of claim 25 further comprising positioning said die proximate a distal end of a barrel portion of a housing and positioning the distal end proximate the mouth of a patient to cure a compound.

29. The method of claim 25 further comprising supporting the die in a housing and coupling the optically reflective element with a sleeve, the sleeve being configured to be removably mounted with respect to the housing.

30. The method of claim 25 further comprising emitting a power density of light in the range of 200 to 1400 mW/cm².

31. The method of claim 25 further comprising positioning a non-imaging optical focusing device with the optically reflective element for further reflecting light from the element and directing it onto a compound for directing light from the array into the optical device.

32. The method of claim 31 wherein said non-imaging optical focusing device is a collimating total internal reflection (TIR) lens.

33. The method of claim 25 further comprising supporting the die in a housing and positioning a removable sleeve with respect to the housing.

34. The method of claim 33 wherein the removable sleeve is made of a disposable material.

35. The method of claim 33 wherein the removable sleeve is made of an autoclavable material to be sterilized after a use.

36. The method of claim 25 further-comprising intercepting the light emitted by the array of die with a plurality of optically reflective elements.

37. The method of claim 36 wherein said light-emitting die emits light in the range of 0°-180° and said optically reflective element collimating the light into a beam which does not diverge significantly from said acceptance angle.

38. The method of claim 25 further comprising directing light from the die into a light transmitting device having an acceptance angle, and collimating the light with the optically reflective element into a beam which does not diverge significantly from said acceptance angle prior to directing the light into the light transmitting device.

39. An instrument for curing light-curable compounds which are curable in the mouth of a patient, the instrument comprising:

18

a plurality of solid state, light-emitting die, the die each being a semiconductor junction individually mounted on a substrate and free of an integral reflector to form an array operable for emitting light having wavelengths within a narrow band of wavelengths;

a non-fiber reflective element coupled to surround an outer edge of the substrate and the array of light emitting die for reflecting the light emitted collectively from the die array and directing it toward a compound for curing the compound.

40. An instrument for curing light-curable compounds which are curable in the mouth of a patient, the instrument comprising:

a plurality of solid state, light-emitting die forming an array, each of the die being a semiconductor junction mounted on a substrate without individual packaging, the array of die operable for collectively emitting light having wavelengths within a narrow band of wavelengths;

an optically reflective element coupled to surround an outer edge of the array of light emitting die for reflecting the light emitted collectively from the array of die and directing it toward a compound for curing the compound.

41. An instrument for curing light-curable compounds which are curable in the mouth of a patient, the instrument comprising:

a housing comprising a barrel portion having a proximal end and a distal end, the distal end configured to be positioned proximate to the mouth of a patient;

a plurality of solid state, light-emitting die, the die each being a semiconductor junction individually mounted on a substrate to form an array operable for emitting light having wavelengths within a narrow band of wavelengths;

an optically reflective element coupled to surround an outer edge of the substrate and the array of light emitting die for reflecting the light emitted collectively from the die array;

the light-emitting die array and optically reflective device being mounted proximate the distal end of the barrel portion and the reflective element operable for directing light out of the distal end and toward a compound for curing the compound.

42. An instrument for curing light-curable compounds which are curable in the mouth of a patient, the instrument comprising:

a plurality of solid state, light-emitting die, the die each being a semiconductor junction individually mounted on a substrate to form an array operable for emitting light having wavelengths within a narrow band of wavelengths;

an optically reflective element coupled to surround an outer edge of the substrate and the array of light emitting die for reflecting the light emitted collectively from the die array;

the optically reflective element being configured to couple with an end of a light directing device which directs the reflected light from the optically reflective element in a beam toward a compound for curing the compound.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,692,251 B1
DATED : February 17, 2004
INVENTOR(S) : Joseph N. Logan and Raymond L. Knox

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 5,

Line 31, reads "In accordance With one aspect of the present invention, an...." and should read -- In accordance with one aspect of the present invention, an.... --.

Column 15,

Line 51, reads "...emitting die for reflecting the light emitted collectively..." and should read -- ...emitting die for capturing the light emitted collectively... --.

Column 17,

Line 13, reads "...emitting die for reflecting the light emitted collectively..." and should read -- ...emitting die for capturing the light emitted collectively... --.

Column 18,

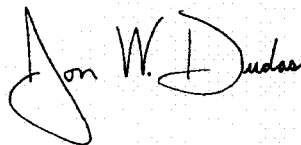
Line 9, reads "...emitting die for reflecting the light emitted collectively..." and should read -- ...emitting die for capturing the light emitted collectively... --.
Lines 21-22, read "...outer edge of the array of light emitting die for reflecting the light emitted collectively from the array of die..." and should read -- ...outer edge of the array of light emitting die for capturing the light emitted collectively from the array of die... --.

Lines 41 and 58, reads "...emitting die for reflecting the light emitted collectively..." and should read -- ... emitting die for capturing the light emitted collectively.... --.

Line 62, reads "...reflected light from the optically reflective element in a..." and should read -- ... captured light from the optically reflective element in a.... --.

Signed and Sealed this

Second Day of August, 2005



JON W. DUDAS
Director of the United States Patent and Trademark Office



US007066733B2

(12) **United States Patent**
Logan et al.

(10) **Patent No.:** **US 7,066,733 B2**
(45) **Date of Patent:** **Jun. 27, 2006**

(54) **APPARATUS AND METHOD FOR CURING MATERIALS WITH LIGHT RADIATION**

(75) Inventors: **Joseph N. Logan**, Trumbull, CT (US);
Raymond L. Knox, Bethel, CT (US)

(73) Assignee: **Kerr Corporation**, Orange, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/655,781**

(22) Filed: **Sep. 5, 2003**

(65) **Prior Publication Data**

US 2005/0003322 A1 Jan. 6, 2005

Related U.S. Application Data

(63) Continuation of application No. 09/632,260, filed on Aug. 4, 2000, now Pat. No. 6,692,251, which is a continuation-in-part of application No. 09/009,205, filed on Jan. 20, 1998, now Pat. No. 6,200,134.

(51) **Int. Cl.**

A61C 1/00 (2006.01)
A61C 3/00 (2006.01)

(52) **U.S. Cl.** **433/29; 362/119**

(58) **Field of Classification Search** **433/29,**
433/215; 606/1, 13, 16; 607/88; 362/119,
362/800, 804

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,638,013 A 1/1972 Keller 240/41.15
3,712,984 A 1/1973 Lienhard
3,733,481 A 5/1973 Kuyt
3,868,513 A 2/1975 Gonser 250/504
3,970,856 A 7/1976 Mahaffey et al. 250/493
4,048,490 A 9/1977 Trouc 240/41.35
4,114,274 A 9/1978 Jones

4,114,946 A 9/1978 Hoffmeister et al.
4,149,086 A 4/1979 Nath
4,184,196 A 1/1980 Moret et al. 433/29
4,185,891 A 1/1980 Kaestner 350/167

(Continued)

FOREIGN PATENT DOCUMENTS

DE 42 11 233 1/1992

(Continued)

OTHER PUBLICATIONS

Burgess, John O. et al., *An Evaluation of Four Light-Curing Units Comparing Soft and Hard Curing*, Pract. Periodont Aesthet. Dent. 11(1), 125-132, 1999.

(Continued)

Primary Examiner—Ralph A. Lewis

(74) Attorney, Agent, or Firm Wood, Herron & Evans, L.L.P.

(57) **ABSTRACT**

An instrument and method for curing light-curable compounds in the mouth of a patient, the instrument comprising a housing and a plurality of solid state, light-emitting elements on a substrate supported by the housing. The elements form a collective array on the substrate operable for collectively emitting light having wavelengths within a narrow band of wavelengths.

An optical focusing device is positioned to intercept the light emitted by the array of elements and includes a non-imaging optical device which is operable for collimating the light from the array into a beam to be directed onto a compound for curing the compound. A disposable sleeve covers the housing and array and may incorporate the optical focusing device. The sleeve is removed and discarded after use to eliminate the need to autoclave the instrument.

18 Claims, 3 Drawing Sheets

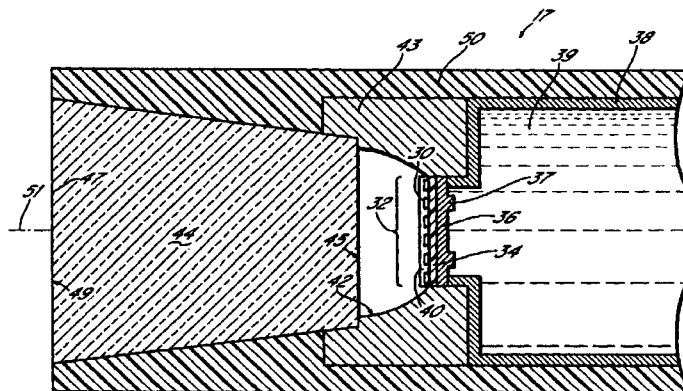


EXHIBIT B

US 7,066,733 B2

Page 2

U.S. PATENT DOCUMENTS

4,186,748 A	2/1980	Schlager	128/736	5,747,363 A	5/1998	Wei et al.	438/5
4,209,907 A	7/1980	Tsukada et al.		5,759,032 A	6/1998	Bartel	
4,229,658 A	10/1980	Gonser		5,803,729 A	9/1998	Tsimerman	
4,230,453 A	10/1980	Reimers	433/29	5,857,767 A	1/1999	Hochstein	
4,233,649 A	11/1980	Scheer et al.		5,912,470 A	6/1999	Eibofner et al.	
4,280,273 A	7/1981	Vincent		5,928,220 A	7/1999	Shimoji	
4,298,806 A	11/1981	Herold	250/504	5,975,895 A	11/1999	Sullivan	
4,337,759 A	7/1982	Popovich et al.	126/438	6,008,264 A	12/1999	Ostler et al.	522/4
4,385,344 A	5/1983	Gonser	362/32	6,033,223 A	3/2000	Narusawa et al.	
4,391,588 A	7/1983	Matsui		6,045,240 A	4/2000	Hochstein	
4,398,885 A	8/1983	Loge et al.	433/126	6,046,460 A	4/2000	Mertins	
4,412,134 A	10/1983	Herold et al.		6,065,965 A	5/2000	Rechmann	
4,445,858 A	5/1984	Johnson		6,068,474 A	5/2000	Senn et al.	
4,450,139 A	5/1984	Bussiere et al.	422/186.3	6,077,073 A	6/2000	Jacob	
4,610,630 A	9/1986	Betush		6,086,367 A	7/2000	Levy	
4,666,406 A	5/1987	Kanca, III	433/229	6,095,812 A	8/2000	Senn et al.	
4,673,353 A	6/1987	Nevin		6,102,696 A	8/2000	Osterwalder et al.	
4,716,296 A	12/1987	Bussiere et al.		6,123,545 A	9/2000	Eggler et al.	
4,729,076 A	3/1988	Masami et al.	362/235	6,155,823 A	12/2000	Nagel	
4,757,381 A	7/1988	Cooper et al.		6,159,005 A	12/2000	Herold et al.	
4,792,692 A	12/1988	Herold et al.		6,161,937 A	12/2000	Rosenstatter	
4,810,194 A	3/1989	Snedden	433/91	6,168,431 B1	1/2001	Narusawa et al.	
4,826,431 A	5/1989	Fujimura et al.	433/29	6,171,105 B1	1/2001	Sarmadi	
4,836,782 A	6/1989	Gonser		6,186,786 B1	2/2001	Trushkowsky	
4,839,566 A	6/1989	Herold et al.		6,193,510 B1	2/2001	Tsimerman	
4,846,546 A	7/1989	Cuda	350/96.24	6,200,134 B1	3/2001	Kovac et al.	433/29
4,888,489 A	12/1989	Bryan	250/504	6,208,788 B1	3/2001	Nosov	
4,935,665 A	6/1990	Murata	313/500	6,220,722 B1	4/2001	Begemann	
4,936,808 A	6/1990	Lcc	445/24	6,280,187 B1	8/2001	Slone	
4,948,215 A	8/1990	Friedman		6,280,188 B1	8/2001	Ross	
4,963,798 A	10/1990	McDermott	315/312	6,331,111 B1	12/2001	Cao	
4,999,310 A	3/1991	Kim	437/51	6,345,982 B1	2/2002	Meyer	
5,003,434 A	3/1991	Gonser et al.	362/32	6,379,149 B1	4/2002	Franetzki	
5,007,837 A	4/1991	Werly		6,419,483 B1	7/2002	Adam et al.	
5,017,140 A	5/1991	Ascher		6,439,888 B1	8/2002	Boutoussov et al.	
5,029,957 A	7/1991	Hood	350/96.2	6,468,077 B1	10/2002	Melikechi et al.	
5,115,761 A	5/1992	Hood	118/641	6,692,251 B1 *	2/2004	Logan et al.	433/29
5,147,204 A	9/1992	Patten et al.	433/229	2001/0007739 A1	7/2001	Eibofner et al.	
5,150,016 A	9/1992	Sawase et al.	315/294	2001/0046652 A1	11/2001	Ostler et al.	
5,161,879 A	11/1992	McDermott	362/206	2002/0014864 A1	2/2002	Gemunder et al.	
5,162,696 A	11/1992	Goodrich	313/511	2002/0051367 A1	5/2002	Hlooker et al.	
5,173,810 A	12/1992	Yamakawa		2002/0133970 A1	9/2002	Gordon et al.	
5,198,678 A	3/1993	Oppawsky		2003/0015667 A1	1/2003	MacDougald et al.	
5,201,655 A	4/1993	Friedman	433/29	2003/0036031 A1	2/2003	Lieb et al.	
5,233,283 A	8/1993	Kennedy	320/13	2003/0219693 A1	11/2003	Cao	
5,242,602 A	9/1993	Richardson et al.	210/745				
5,265,792 A	11/1993	Harrah et al.	228/6.2				
5,278,629 A	1/1994	Schlager et al.	356/313				
5,283,425 A	2/1994	Imamura	250/208.1				
5,290,169 A	3/1994	Friedman et al.	433/29				
5,302,124 A	4/1994	Lansing et al.					
5,312,249 A	5/1994	Kennedy					
5,316,473 A	5/1994	Hare	433/29				
5,328,368 A	7/1994	Lansing et al.					
5,371,826 A	12/1994	Friedman	385/115				
5,373,114 A	12/1994	Kondo et al.	174/268				
5,420,768 A	5/1995	Kennedy	362/119				
5,457,611 A	10/1995	Verderber					
5,471,129 A	11/1995	Mann	320/21				
5,487,662 A	1/1996	Kipke et al.	433/37				
5,521,392 A	5/1996	Kennedy et al.	250/492.1				
5,530,632 A	6/1996	Shikano et al.					
5,535,230 A	7/1996	Abe	372/43				
5,616,141 A	4/1997	Cipolla					
5,617,492 A	4/1997	Beach et al.	385/33				
5,634,711 A	6/1997	Kennedy et al.	362/119				
5,660,461 A	8/1997	Ignatius et al.	362/241				
5,664,042 A	9/1997	Kennedy	385/136				
5,698,866 A	12/1997	Doiron et al.	257/99				
5,707,139 A	1/1998	Haitz	362/231				
5,711,665 A	1/1998	Adam et al.	433/9				

FOREIGN PATENT DOCUMENTS

DE	295 11 927	2/1997
EP	0 116 405	8/1984
EP	0 266 038	10/1991
EP	0 568 666	11/1992
EP	0 320 080	8/1993
EP	0 672 435	9/1995
EP	0 678 282	10/1995
EP	0 709 698	5/1996
EP	0 755 662	7/1996
EP	0 736 307	10/1996
EP	0 780 101	6/1997
EP	0 780 103	6/1997
EP	0 830 850	3/1998
EP	0 879 582	11/1998
EP	0 880 945	12/1998
EP	0 884 025	12/1998
EP	0 885 025	12/1998
EP	0 998 880	5/2000
EP	1 031 326	8/2000
EP	1 090 607	4/2001
EP	1 090 608	4/2001
EP	1 093 765	4/2001
EP	1 103 232	5/2001
EP	1 112 721	7/2001
EP	1 138 276	10/2001

US 7,066,733 B2

Page 3

EP	1 138 349	10/2001
EP	0 830 851	5/2002
EP	0 830 852	5/2002
EP	1 206 923	5/2002
EP	1 228 738	8/2002
EP	0 740 567	11/2002
GB	2 212 010	7/1989
GB	2 329 756	3/1999
JP	6-30275	9/1995
JP	8-141001	6/1996
JP	9-10238	1/1997
JP	9010238	* 1/1997
JP	8-194786	2/1997
JP	410033573	2/1998
JP	2 080 522	11/1999
WO	WO 83/01311	4/1983
WO	WO 84/04463	11/1984
WO	WO 92/02275	2/1992
WO	WO 93/09847	5/1993
WO	WO 93/21842	11/1993
WO	WO 95/07731	3/1995
WO	WO95/19810	7/1995
WO	WO 95/26217	10/1995
WO	WO/97/36552	10/1997
WO	WO 97/37722	10/1997
WO	WO 97/46279	12/1997
WO	WO 97/46280	12/1997
WO	WO 98/03131	1/1998
WO	WO 98/04317	2/1998
WO	WO 99/09071	2/1999
WO	WO 99/11324	3/1999
WO	WO 99/16136	4/1999
WO	WO 99/20346	4/1999
WO	WO 99/35995	7/1999
WO	WO 00/01464	1/2000
WO	WO 00/02491	1/2000
WO	WO 00/13608	3/2000
WO	WO 00/15296	3/2000
WO	WO 00/41726	7/2000
WO	WO 00/41767	7/2000
WO	WO 00/41768	7/2000
WO	WO 00/43067	7/2000
WO	WO 00/43068	7/2000
WO	WO 00/43069	7/2000
WO	WO 00/45733	8/2000
WO	WO 00/67048	11/2000
WO	WO 00/67660	11/2000
WO	WO 01/03770	1/2001
WO	WO 00/14012	3/2001
WO	WO 01/19280	3/2001
WO	WO 01/24724	4/2001
WO	WO 01/54770	8/2001
WO	WO 01/60280	8/2001
WO	WO 01/64129	9/2001
WO	WO 01/68035	9/2001
WO	WO 01/69691	9/2001
WO	WO 02/06723	1/2002
WO	WO 02/09610	2/2002
WO	WO 02/11640	2/2002
WO	WO 02/32505	4/2002
WO	WO 02/33312	4/2002
WO	WO 02/49721	6/2002
WO	WO 02/056787	7/2002
WO	WO 02/069839	9/2002
WO	WO 02/080808	10/2002

OTHER PUBLICATIONS

- Davidson-Kaban, Saliha S. et al., *The Effect of Curing Light Variations on Bulk Curing and Wall-to-Wall Quality of Two Types and Various Shades of Resin Composites*, Dent. Mater. 13: 344-352, Nov. 1997.
- European Search Report, Feb. 27, 2004.
- Feltzer, A. J. et al., *Influence of Light Intensity on Polymerization Shrinkage and Integrity of Restoration-Cavity Interface*, Eur. J. Oral Sciences, 103: 322-326, 1995.
- Kanca, III, John and Suh, Byoung I., *Pulse Activation: Reducing Resin-Based Composite Contraction Stresses at the Enamel Cavo-surface Margins*, Am. J. of Dentistry, 12(3), 107-112, 1999.
- Kato, Hiromasa, *Relationship Between the Velocity of Polymerization and Adaptation to Dentin Cavity Wall of Light-Cured Composite*, Dental Materials J. 6(1): 32-37, 1987.
- Koran, Peter and Kurschner, Ralf, *Effect of Sequential versus Continuous Irradiation of a Light-Cured Resin Composite on Shrinkage, Viscosity, Adhesion, and Degree of Polymerization*, Am. J. of Dentistry, 11, No. 1, 17-22, 1998.
- LumiLeds Lighting LLC, *Concept Evaluation Data Luxeon™ Star 5-Watt*, Luxeon™ 5-Watt Preliminary Target Data Sheet, Publication No. JP10 (Jan. 2002).
- LumiLeds Lighting LLC, *LED Application Note Dental Light Curing*, LumiLeds Lighting Publication No. XXX(03.01), Copyright© 2000.
- LumiLeds Lighting LLC, *Application Bulletin AB XXX*, Luxeon™ Data Sheet, Publication No. xxxx-xxxx.
- LumiLeds Lighting LLC, *Luxeon™ Power Light Sources of the Future*, Jan. 2001—Mike Holt.
- LumiLeds Lighting LLC, *Lumen Maintenance of White Luxeon™ Power Light Sources*, Application Brief AB07, LumiLeds Lighting, US LLC.
- LumiLeds Lighting LLC, *Application Note 1149-5, Secondary Optics Design Considerations for Super Flux LEDs*, Copyright© 2000 LumiLeds Lighting, Obsolete Publication No. 5968-1215E, Publication No. AN06 (Mar. 2000).
- Luxcon Dental Technical Data, *Power Light Source*, Apr. 2002.
- Mayes, Joe H., *Curing Lights: An Overview*, Unknown, p. 15-17.
- Mehl, A. et al., *Physical Properties and Gap Formation of Light-Cured Composites With and Without 'Softstart-Polymerization'*, J. of Dentistry, 25, 321-330, 1997.
- Sakaguchi, Ronald L. and Berge, Hong Xu, *Reduced Light Energy Density Decreases Post-Gel Contraction While Maintaining Degree of Conversion in Composites*, J. of Dentistry, 26, 695-700, 1998.
- Schlager, Kenneth J., Ignatius, Ronald W., *An LED-Array Light Source for Medical Therapy*, SPIE vol. 1892 Medical Lasers and Systems II (1993) p. 26-35.
- Swift Jr., Edward J. et al., Ed., *Contemporary Photocuring Issues, Part II*, J. Esthetic Dentistry, 12 (1), 50-57, 2000.
- Tarle, Z. et al., *The Effect of the Photopolymerization Method on the Quality of Composite Resin Samples*, J. of Oral Rehab. 25: 436-442, 1998.
- TIR Technologies, Inc., *Miniaturized TIR lenses for Light Emitting Diodes*, TIR Technical Publication, pp. 1-14.
- Uno, Shigeru and Asmussen, Erik, *Marginal Adaptation of a Restorative Resin Polymerized at Reduced Rate*, Scand J. Dent. Res. 1991; 99: 440-4.

* cited by examiner

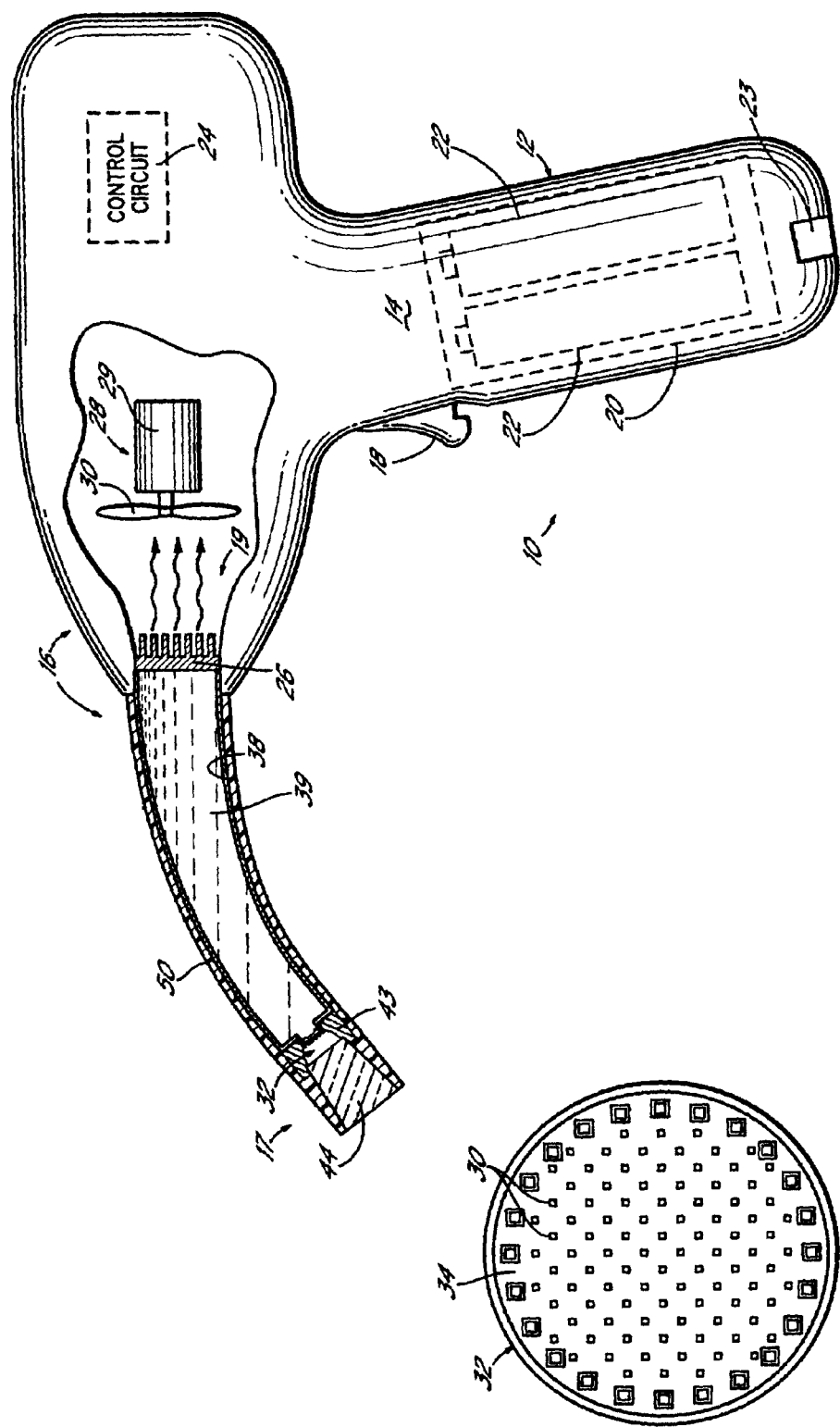


FIG. 1

FIG. 2B

U.S. Patent

Jun. 27, 2006

Sheet 2 of 3

US 7,066,733 B2

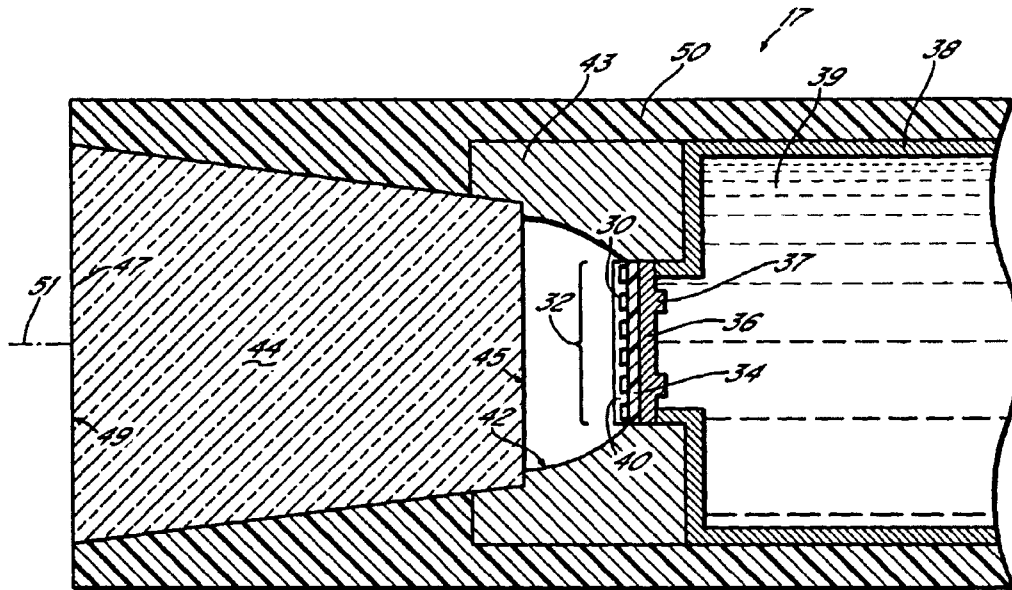


FIG. 2

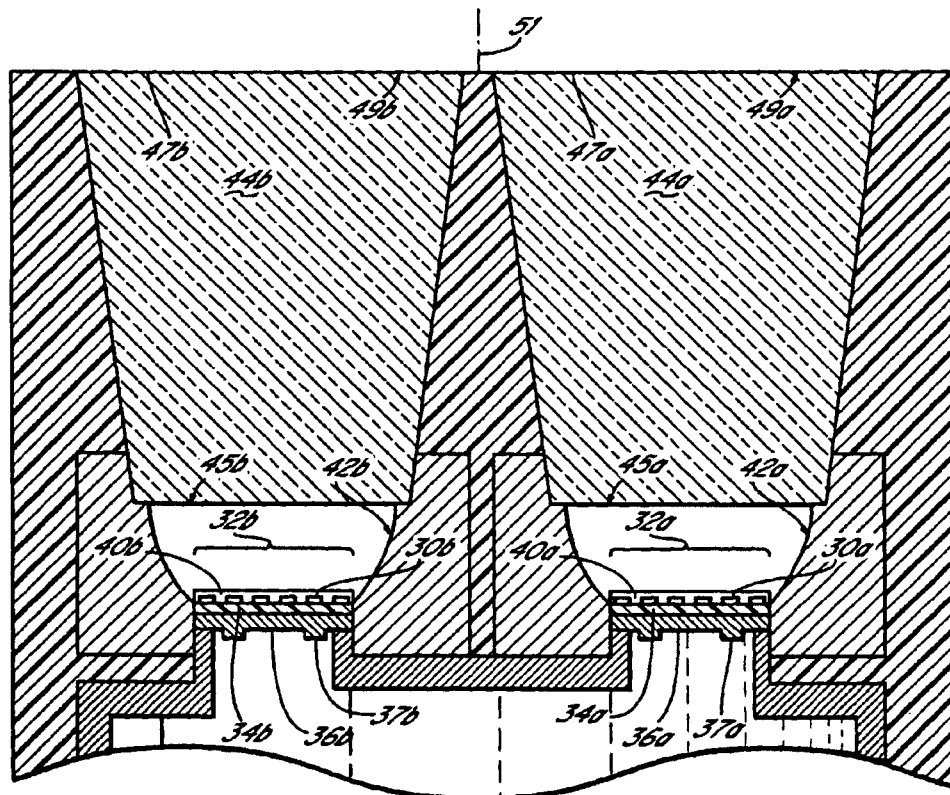
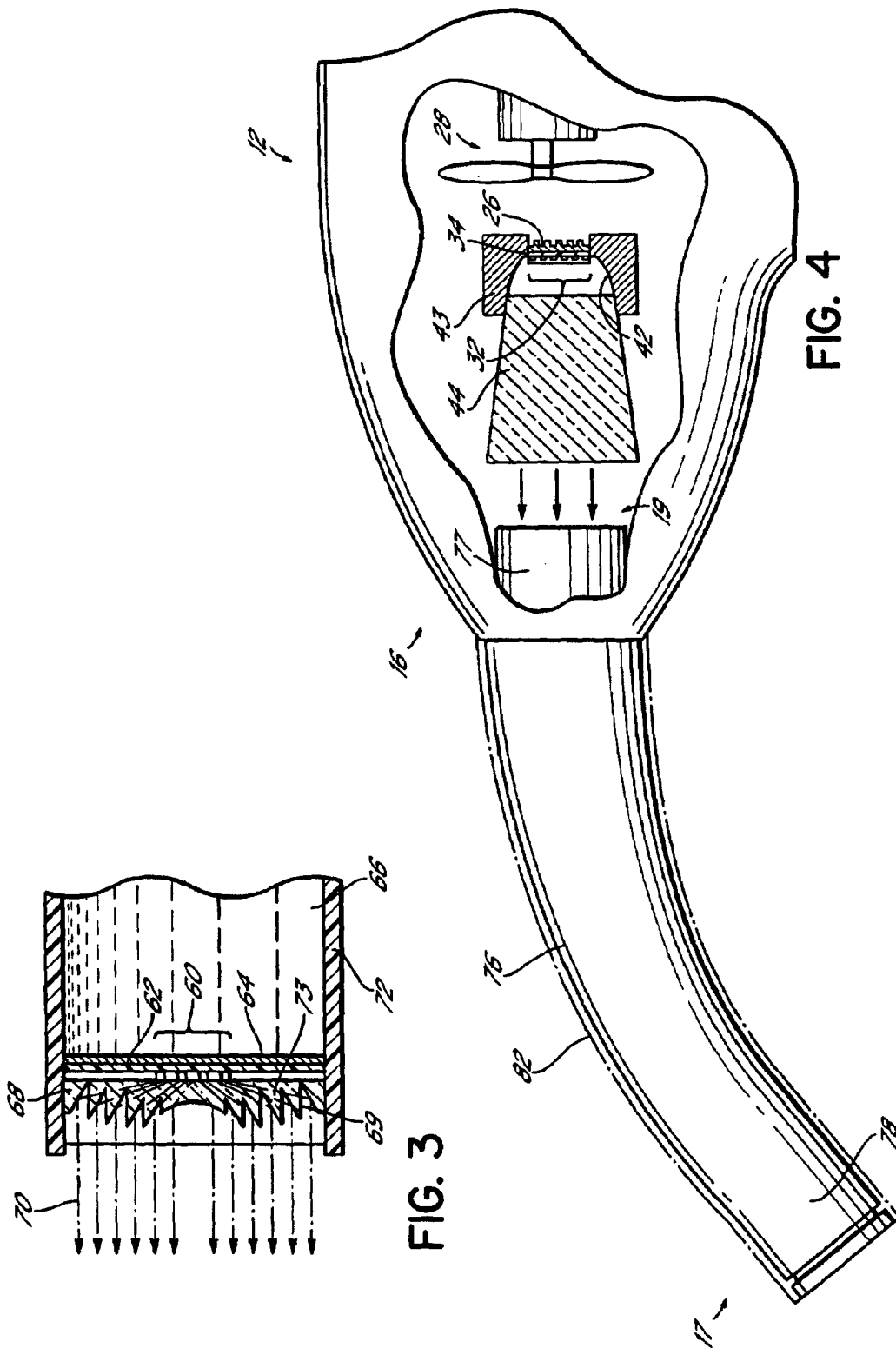


FIG. 2A



US 7,066,733 B2

1

**APPARATUS AND METHOD FOR CURING
MATERIALS WITH LIGHT RADIATION****RELATED APPLICATIONS**

This application is a continuation of U.S. Ser. No. 09/632,260, filed on Aug. 4, 2000, now U.S. Pat. No. 6,692,251 and entitled "Apparatus and Method for Curing Materials with Light Radiation," which, in turn, is a continuation-in-part of U.S. Ser. No. 09/009,205, now U.S. Pat. No. 6,200,134, filed on Jan. 20, 1998 and issued on Mar. 13, 2001, which application and patent are incorporated herein by reference in their entireties.

FIELD OF THE INVENTION

This application is related to the curing of materials with radiation and, more specifically, to curing dental coating and filling compounds with light.

BACKGROUND OF THE INVENTION

Curable adhesive compounds and bonding or filling compounds are widely used for structurally connecting object surfaces together or for filling gaps, openings and cavities in an object surface. Such curable compounds are generally manipulated and positioned on the object surface in a semi-solid state and are then hardened or cured in position to a more solid and permanent state. The curing or hardening of applicable compounds is generally a chemical process which is promoted and driven by one or more curing conditions or factors. For example, the curing process may be driven by exposure of the semi-solid compound and components thereof to air or by exposure of such a compound and its components to an energy source, such as a heat source.

Other curable adhesive and filling compounds are cured by exposure to radiated energy, such as visible and non-visible light energy. Such compounds, referred to as light-curable compounds, are manipulated in a semi-solid form into an area or onto a work surface. Light radiation, preferably in the form of a light beam at a specific wavelength or band of wavelengths, is then directed onto the compound. The compound includes light-sensitive chemical components therein which, when exposed to the light at the specific wavelength, promote the curing or hardening of the compound in the desired position on the work surface to bond, fill, or coat the surface.

As an example, light-curable filling and adhesive compounds are widely used in dental procedures. Dentists use light-curable dental compounds for coating and sealing tooth surfaces, filling caries and other cavities in the tooth surface, and securing crowns and various other dental structures to a tooth surface. Conventionally, dental compounds are cured by exposure to light in the blue range of the spectrum. Once cured, the dental compound reduces further tooth decay, bonds the dental structure, and/or provides additional structure to a tooth. Therefore, it is important that the compounds are completely cured.

More specifically, for curing light-curable dental compounds, visible blue light, and particularly a blue light beam from a hand-held curing light device, is directed onto a tooth surface containing the desired compound layer. The blue light penetrates into the compound layer on the tooth surface for complete curing. The duration of the exposure to blue light for proper curing of the compound layer is dictated by the type of compound and the thickness of the compound

2

layer, as well as the power level and characteristics of the blue light from the curing light device. For example, a thin tooth surface coating or veneer will require less radiated light power, while thicker, deeper fillings for caries and other cavities will require a greater amount of radiated power directed onto the tooth surface for proper curing.

While light-curable compounds have shown very beneficial results in the dental field, existing techniques and dental curing light devices utilized to deliver the light to the tooth surface have various drawbacks. For example, existing dental curing devices require specific filtering mechanisms. Filtering must be done for several reasons. First, it is known that certain wavelengths of blue light are harmful to human tissue. While attempts are made to direct the light beam only on to the tooth surface, a certain amount of oral tissue exposure to the light is inevitable. Therefore, harmful wavelengths must be filtered. Additionally, light-curable compounds are usually sensitive to light having a somewhat specific wavelength, such as a specific blue light wavelength with currently available dental compounds. Therefore, a dental curing light filtering device is tuned to emit light at the proper wavelengths for both patient safety and proper curing.

Many existing conventional dental curing lights use broad spectrum lamp elements, such as halogen bulbs. As a result, dental curing lights must utilize special and complicated filtering devices or filters which receive the broad spectrum light from the lamp element, and then filter the light to provide only the light at the desirable wavelengths. Available lamp elements deliver a wide spectrum of radiation, including visible light, UV light, and infra-red light. Therefore, prior art curing techniques and light devices have generally been very inefficient, because a large amount of the radiated light power is lost simply due to filtering of a significant part of the light spectrum. For example, the input power to a conventional halogen bulb may typically be around 80 Watts, whereas the output power from the dental light device of light at the desired blue wavelength, for example 400–500 nanometers, is typically less than one-half (0.5) Watt.

Additionally, the efficiency of the prior art dental curing lights is further degraded by power losses due to the angle of incidence of the radiated light upon the filtering element. For example, many prior art curing lights utilize reflective filters which reflect only the light at the desirable wavelengths, such as blue light, onto the tooth surface and dental compound. Light at the undesirable wavelengths is passed through the filter to a light absorbing component where it is dissipated. If the angle of incidence of the light from the halogen bulb varies significantly from the desired angle of incidence for the filtering element surface (e.g., 45°), then a reduced amount of the desirable light is reflected onto the tooth surface. This further decreases the amount of desirable light power which is available for curing the dental compound. Conversely, a higher amount of light at undesirable wavelengths may also be reflected onto the tooth surface, rather than being transmitted through the filtering element to be dissipated.

Still another drawback with prior art curing lights is that they generate significant amounts of heat and therefore require complicated cooling systems to operate within the proper temperature range. The significant amount of light energy at the undesirable wavelengths, which is generated by the halogen bulb, must be filtered or otherwise captured. The captured or filtered energy is then dissipated in the form

US 7,066,733 B2

3

of heat. Therefore, power absorbing and heat dissipating elements are required within conventional curing light devices.

Thermal shields are often utilized in conjunction with reflective filters to absorb and dissipate the unreflected, unused light energy in the form of heat. The high power output required for the halogen bulb to produce the desired light power level for curing, creates a significantly high thermal load on the shields. The shields must then be cooled. Generally, fan elements are used in the dental light device to provide convective cooling to the shields. The additional cooling elements increase the size of the light device and complicate its design. As will be appreciated, it is desirable to keep the light device as small and maneuverable as possible, since it is hand-held and used in a patient's mouth.

Additionally, a thermal load is also placed on the reflective filter element, which must then also be cooled, such as by heat sinks and fans. The absorption devices and heat dissipating systems not only complicate the operation and design of the light device, but also make it more expensive to produce, and more subject to operational failure.

Another drawback of prior art dental curing light devices is the limited operational life of the lamp element, such as a halogen bulb. The bulbs frequently burn out and must be replaced. Furthermore, the heat generated inside the light device, which is usually enclosed, shortens the effective operational lifespan of the bulb.

Attempts have been made in the prior art to address some of these drawbacks. For example, Japanese Patent Applications No. 6-30275, 6-285508, 7-163863, and 8-194786; U.S. Pat. Nos. 5,420,768 and 5,634,711; and U.K. patent application No. GB 2,329,756, all disclose various devices using packaged, conventional light-emitting diodes or LEDs, to provide a curing light source with light in the desirable blue range. While specific blue light is provided by the LEDs without significant filtering, various of these devices require complicated internal designs for focusing of the curing light, or require specific electronic control of the LEDs. Furthermore, large numbers of conventional LEDs are necessary. As illustrated in the Figures of those applications, the solid state LED elements are spread out over a circuit board or other support structure and require a somewhat large housing to contain all of the conventional LEDs necessary for generating the intensity of light which is required for practical curing uses. Therefore, it has been difficult to provide a suitable curing light using conventional LEDs, which will generate sufficient curing power in a small incomplete design.

Using traditional packaged LEDs, as disclosed in the above-cited art, has specifically presented difficulties associated with generating sufficient curing power within a reasonably sized device which may be adequately cooled. Further complications with such devices have resulted from attempts to concentrate the light from the large grouping of traditional LEDs into a small area and at a sufficient power density so as to be useful for curing. Such difficulties in providing a suitable curing light device utilizing the existing traditional packaged LED technology is highlighted by the lack of a well-received and widely-utilized dental curing light on the market which utilizes such technology.

Alternatively, the devices and technology disclosed in U.S. patent application Ser. No. 09/009,205, noted above, have provided a curing device with solid state, light-emitting components which generate sufficient curing power densities in a reasonably-sized device that may be properly cooled. Further efforts by the inventors of the present application are continuing to improve the existing technol-

4

ogy disclosed in that earlier application and to provide the desirable curing power density, size and thermal characteristics required for a successful commercial curing device.

Still another drawback associated with prior art curing lights is their inefficiency in transmitting the light to the work surface, such as a tooth surface, once the light has been generated by the element or bulb. The light is generated within the main housing of the curing light, and must be transmitted to an output end of the housing. Existing dental curing lights utilize elongated light guides to deliver light from the light generating elements inside the housing to the tooth.

Light guides are usually comprised of a large number of optical fibers fused together into an elongated guide. The air/glass interfaces between the generating elements and the input end of the light guide and the output end of the light guide and the inside of the mouth are inefficient and may produce approximately a 10% loss in power per interface. Furthermore, prior art devices may utilize a converging lens to focus light into the input end of the light guide. This provides another lossy interface encountered by the light. Such inefficiencies further increase the cure time that is necessary, and/or create the need for higher power (and associated heat) to provide the necessary curing light intensity.

Another concern with dental curing lights is that such lights are medical/dental instruments, and a portion of the instrument is introduced into a cavity of the body, i.e. the mouth. Since the same curing light will be utilized with different patients, cross-contamination between patients must be avoided. Accordingly, sterilization of the curing light, or a portion thereof, has been necessary with conventional devices. Sterilization, often referred to as autoclaving, requires additional equipment which must be purchased and maintained by the dentist or other physician. Sterilization also introduces an extra step in between curing procedures. Furthermore, the high heat required for sterilization may, over time, damage components of the curing light. Accordingly, conventional curing lights must be designed to withstand sterilization and the high temperatures associated therewith or to otherwise address the sterilization issue.

Accordingly, it is an objective of the present invention to provide a simple, durable curing light device for hardening or curing light-curable compounds. Particularly, it is an objective to provide such a curing light device for curing dental compounds used for dental fillings and coatings.

It is another objective to provide a curing light utilizing solid state light elements.

It is another objective to provide a curing light which has a compact and simple design and which is capable of providing a light power density that is useful for practical curing applications.

It is still another objective of the present invention to cure compounds with curing lights utilizing less power and having greater efficiency to reduce the amount of heat energy generated by the device and thus reduce the heat energy which must be dissipated. Furthermore, it is desirable to provide more efficient cooling of the light-generating devices.

It is still another objective of the invention to eliminate the necessity of reflective filters and other filter elements within a light device for curing light-curable compounds.

It is still another objective to address the need for sterility within a curing light.

It is still a further objective to provide a blue light device which operates within a small space and is easily manipulated within the mouth of a dental patient.

US 7,066,733 B2

5

These objectives and various other objectives will become more readily apparent from the Description of the Invention below.

SUMMARY OF THE INVENTION

An instrument and method for curing light-curable compounds, such as dental compounds in the mouth of a patient, comprises a housing which supports a plurality of solid state, light-emitting elements. The elements are preferably light-emitting dies formed of a semiconductor material. The elements are mounted on a substrate supported by the housing to form a collective array which is operable for collectively emitting light having a wavelength within a narrow band of wavelengths. In one embodiment of the invention, the narrow band of wavelengths includes that of the blue wavelength. However, other wavelengths might also be utilized, depending upon the light sensitivity of the curable compound utilized.

One suitable housing for the invention includes a gun-shaped housing which has a handle portion and a barrel portion. The handle portion is held by an operator and the barrel portion is directed toward a work surface, such as a tooth. A portable power supply may be utilized within the housing such that the instrument is a hand-held instrument which is completely portable. In one embodiment of the invention, the array of light-emitting elements is positioned on the distal end of the barrel portion of the housing which is placed within the mouth of a patient so that the light is delivered directly to a work surface, such as a tooth. In an alternative embodiment, the array of elements may be positioned in the housing such that the generated light must be transmitted to the distal end, such as by an optical fiber light guide.

In accordance with one aspect of the present invention, an optical focusing device is positioned to intercept the light emitted by the array of elements. The optical focusing device is a non-imaging optical device which is operable for collimating the light from the array into a beam to be directed on to a compound for curing the compound. The non-imaging device efficiently collimates and transmits the light from the array to a work surface without inefficiencies associated with imaging lenses in the prior art. A reflective element may be positioned between the array and the optical focusing device for further efficiently directing light from the array into the optical focusing device to be collimated and delivered to a work surface.

In accordance with another aspect of the present invention, the array of dies is arranged on a substrate in a density which is operable for emitting a power density of light in the range of 200-1400 mW/cm². Such a density provides a desirable curing power to the work surface for a suitable cure. For cooling such an array and the substrate on which the elements are mounted, the present invention utilizes conductive cooling wherein a heat tube containing a heat-conductive liquid is thermally coupled to the substrate for conductively transferring heat generated by the array of elements away from the substrate. In one embodiment of the invention, the heat sink is thermally coupled to the substrate and the heat tube is then thermally coupled to the heat sink. In that way, heat is conductively transferred away from the substrate and elements. A heat exchanger is coupled to the other end of the heat tube for convectively transferring heat to the air, such as with the utilization of a fan.

In another aspect of the present invention, a disposable sleeve is utilized over a portion of the housing during the curing process. After each curing process, the disposable

6

sleeve may be removed and discarded, thus eliminating the requirement of autoclaving the curing instrument after each use and prior to the next use. In one embodiment of the invention, the non-imaging optical device, such as a non-imaging lens, and a reflective element are coupled to an end of the disposable sleeve. When the sleeve is positioned over a portion of the housing, the reflective element and lens are aligned coaxially with the array collimating light from the array. In such an embodiment, both the non-imaging lens and reflective element are disposable and are discarded with the sleeve after each use.

The array, which comprises a plurality of dies positioned on a flat substrate, generally emits light within a range of 0-180°. When the array is located at the distal end of the housing, the non-imaging lens and reflective element are capable of capturing the light within the 180° range and effectively and efficiently collimating the light into a beam directed to the work surface. When the array is positioned further within the housing, away from the distal end of the housing, and away from the work surface, the non-imaging lens is operable for collimating light within the 180° range into a beam which does not diverge significantly from an acceptance angle of an optical fiber light guide. In that way, light is efficiently directed through the light guide and housing to the distal end of the housing whereupon it is emitted onto a work surface, such as a tooth. Preferably, the array is mounted onto the distal end of the housing for directly delivering light to the work surface. In that way, an optical fiber light guide, which has multiple lossy air/glass interfaces, may be eliminated for efficient transmission of light.

One embodiment of the invention utilizes a single non-imaging optical focusing device for the array of elements. Alternatively, the elements might range in sub-groups on the array and multiple, non-imaging optical devices may be utilized.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with a general description of the invention given below, serve to explain the principles of the invention.

FIG. 1 is a side view in partial cross-section of one embodiment of a curing light device in accordance with the principles of the invention.

FIG. 2 is a side view, in partial cross-section, of a portion of the embodiment of the invention illustrated in FIG. 1.

FIG. 2A is a side view, in partial cross-section, of a portion of another embodiment of the invention.

FIG. 2B is a top view of an array of dies in accordance with one embodiment of the invention.

FIG. 3 is a side view, in partial cross-section, of a portion of another embodiment of the invention.

FIG. 4 is a side view, in partial cross-section, of a portion of another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 illustrates one embodiment of a curing light device or curing light for curing light-curable compounds such as dental compounds in accordance with the aspects of the present invention. In FIG. 1, device 10 includes a housing 12 which is to be manipulated for curing. Housing 12 is generally gun-shaped and includes a handle portion 14 and

US 7,066,733 B2

7

a barrel portion 16. The operator, such as a dentist, grips housing 12 around the handle portion 14 and directs the barrel portion 16 in the direction of the tooth surface (or other work surface) and compound to be cured (not shown). For curing dental filling and coating compounds, the dentist would generally position at least part of the barrel portion in the mouth of a patient with a radiating end 17 of the barrel portion pointing at a particular tooth or teeth. The handle portion 14 includes an operational trigger switch 18 which is operably coupled to a power supply 20 and/or control circuit 24 for selectively operating the device and supplying power to light-emitting elements 32 to generate a curing light beam, as discussed further below. The power supply 20 is shown located in handle portion 14, but might also be located elsewhere in the housing.

In one embodiment of the invention, the power supply is portable and incorporates batteries 22. The batteries could be any suitable type (e.g. lithium batteries), and may be disposable or rechargeable. To that end, housing 12 may include a port 23 for coupling an external charger (not shown) to the power supply 20 to charge rechargeable batteries 22. Alternatively, an external power supply, such as one powered by an AC outlet, may be coupled to power supply 20 to provide the power necessary to operate device 10.

A control circuit 24 is mounted within housing 12 and is operably coupled to the power supply 20, trigger switch 18 and the other components of device 10, such as array 32, for operating and controlling the components. Control circuit 24, for example, may include various electrical circuit components mounted on a circuit board and arranged in a way determined by a person of ordinary skill in the art for providing the desired power and control of device 10. For example, the control circuit 24 will usually include conventional control circuits for a curing light device, such as a timer, for timing the operational radiation cycle for the device when the trigger switch is engaged. A microprocessor may also be utilized for such control, rather than discrete components. It will be readily understood that the control circuit may be configured in various different ways to properly operate curing light 10. In one embodiment, the microprocessor control will regulate the lamp voltage to produce a constant output. In other embodiments, the microprocessor control might be utilized to ramp the power up or down in a selected fashion for proper curing.

Barrel portion 16 is appropriately formed and may include an angled distal or radiating end 17 to direct a curing light beam 21 out of the housing and onto a tooth surface or other work surface. It will be understood by a person of ordinary skill in the art that the shape of housing 12 may also vary. Barrel portion 16 is shown as solid in the Figures; however, it might also be vented for heat dissipation purposes. Furthermore, the barrel portion 16 might be separate from the rest of the housing and removably secured to the housing by any suitable method as is known in the art. For example, the barrel portion 16 might be screw-mounted to the housing 12. Still further, the power supply might be positioned in line with the barrel portion to reduce or eliminate the handle portion and thereby streamline the design, such as for a small, pocket curing light. The housing 12 is formed of a suitable light-weight plastic material such as polysulphone.

FIG. 1 illustrates one embodiment of the present invention in which a beam of radiation or light 21 utilized for curing purposes is generated by an array 32 of light-emitting elements positioned proximate the radiating end 17 of the barrel portion 16. Heat generated by the array 32 is transmitted from the radiating end 17, or distal end, back to a

8

proximal end 19 of the barrel portion, where it is further dissipated. In the embodiment of FIG. 1, a heat tube 38 is thermally coupled to the array 32 and conductively transfers heat generated by the array to a heat exchanger 26, which is then convectively cooled. An appropriate fan 28 with motor 29 and blade 30 may be mounted within the housing 12, as shown in FIG. 1 to assist convective cooling.

More specifically, referring to FIG. 2, the illustrated embodiment of the present invention utilizes a plurality of individual light-emitting dies 30 which are mounted to form a collective array 32 on a substrate 34. The dies 30 are small, bare semiconductor junctions and are constructed using a light generating semiconductor material. The dies 30 are preferably not separately or individually packaged or otherwise mounted with individual integral lenses as are conventional light-emitting diodes or LEDs. Conventional LEDs used in the prior art have integral and individual packages, usually including a reflector and an integrally formed individual lens. The dies of the invention might be used with additional components, such as a clear protective coating 40, which is applied over the dies on substrate 34, or other added components. However, the dies as mounted are essentially bare semiconductor junctions, without prepackaged individual and integral reflectors and lenses, as are found in conventional LEDs.

As noted above, the dies 30 are not individually lensed, as are conventional LEDs. However, they might be covered with a clear protective layer or coating 40 of plastic to improve the durability of the array 32.

The substrate 34 is an electrically insulated substrate which has heat conductive properties. In one embodiment of the invention, substrate 34 may be a sapphire substrate or a diamond which has electrically insulative properties, but which also conducts heat away from the die array 32. For the purposes of uniform light generation within a beam having a generally circular cross-section, the dies of array 30 are preferably arranged in a circular pattern. U.S. patent application Ser. No. 09/009,205, illustrates several circular patterns of dies and light generating elements suitable for an embodiment of the present invention.

The substrate 34 is bonded to a heat sink 36, formed of a suitable thermally conductive material, such as copper. Heat sink 36 is then welded or soldered to one end of a liquid-filled heat tube or pipe 38 for conductively transferring heat generated by the dies 30 away from the heat sink 36, substrate 34 and array 32. A heat conductive liquid 39 contacts the back side of heat sink 36, opposite substrate 34 and array 32 (see FIG. 2), and thermally pulls heat from the sink. Therefore, the die array is effectively conductively cooled using the heat tube 38 and the intermediate elements 34, 36. Heat tube 38, which includes a heat conductive liquid 39 therein, such as saline, is commercially available from Aavid Thermal Technologies.

One particularly unique aspect of the present invention is that the array 32 is conductively cooled to provide adequate heat transfer from the light-generating dies 30. Prior art structures have traditionally relied upon convective cooling in which a heat sink and other heat dissipating devices thermally coupled to the light-generating elements are convectively air cooled, such as by a fan. One particular problem with prior art devices has been the dissipation of heat which is generated by the LEDs or other light-generating elements utilized therein. In the present invention, the heat tube 38 rapidly conductively draws heat away from array 32 and dies 30 for improved cooling characteristics. This allows a sufficient amount of curing light power to be generated for proper curing while maintaining an array

US 7,066,733 B2

9

which does not overheat. The present invention therefore provides improved heat transfer and dissipation capabilities with respect to the prior art.

Referring again to FIG. 1 and the embodiment of the invention which utilizes the array 32 located at the distal, or radiating end 17 of barrel portion 16, the opposite, or proximal, end of the heat tube 38 is thermally coupled to a heat exchanger 36, which is then convectively cooled by fan 28. The heat exchanger, which may be soldered to the heat tube 38, has fins, as shown, over which air is directed. Therefore, the die array 32 is conductively cooled by the heat tube 38 and a liquid therein, and the heat tube is then convectively cooled at the opposite end by air, such as by a fan.

For directing and collimating the beam 21 generated by array 32, the embodiment of the invention illustrated in FIG. 2 utilizes a reflective surface 42, and an optical focusing device 44 to collimate light from the array 32 into a beam to be directed into the mouth of the patient for curing compound therein or to be directed to some other work surface. As shown, the array 32, reflective surface 42 and optical focusing device 44 are all positioned at the distal end of the barrel portion. Thereby, the light is directly radiated onto the work surface and compound. Therefore, the embodiment of FIGS. 1 and 2 eliminates various air-to-object interfaces which tend to be lossy. As such, the present invention more efficiently delivers power from the light generating elements to the work surface. Generally, the radiating or distal end 17 will be positioned in the mouth of the patient to radiate a beam of light directly onto a work surface with a light-curable compound. Prior art devices using light transmitting devices with multiple lossy interfaces often have difficulty in generating sufficient light power densities for curing. The present invention addresses this issue by eliminating various lossy interfaces.

To focus the light from array 32, the curing light device 10 uses a reflective surface or reflector 42 which encircles the array as shown in FIG. 2. In the illustrated embodiment, the reflective surface 42 is formed by an appropriately shaped plastic ring structure 43, which circumferentially surrounds the outer edge of array 32 defined by substrate 34. Reflective surface 42 is generally parabolic in shape and is formed by coating the surface 42 of plastic structure 43 with a reflective coating for the purpose of efficient reflection. A mylar coating, available from 3M, has proven to have suitable properties for that purpose and has an approximately 99% reflective efficiency for the purposes of the present embodiment of the invention illustrated in FIG. 2. As shown in FIG. 2, the plastic ring structure 43 forms the generally parabolic reflective surface 42 around array 32 for directing the light away from the dies 30 and into an input end 45 of the optical focusing device 44.

The optical focusing device, in accordance with one embodiment of the invention, is a non-imaging device. One suitable non-imaging optical focusing device is a non-imaging lens 44 having a generally truncated conical shape, as illustrated in FIG. 2. A non-imaging lens, such as lens 44, receives the light from array 32 at an input end 45 and directs and concentrates the light from array 32 into a focused beam at the output end 47 of the non-imaging lens 44. However, the non-imaging lens does not form an optical image, which is inefficient. A non-imaging optical focusing device as used in the present invention efficiently collimates light so that a desirable light power density is achieved at the work surface, such as a surface of a tooth. The light power density from the array 32 is not reduced by the formation of an image as with traditional optical lenses. One suitable, non-imaging lens is

10

formed of a transparent polycarbonate material. As illustrated, structure 43 is appropriately formed to receive the input end 45 of lens 44 to position the lens in coaxial alignment with the array 32 and surface 42 about axis 51. Each of the lens and surface 42 preferably have generally circular transverse cross sections for efficient transfer of the light along axis 51. One suitable combination of a reflective surface and optical focusing device, which are operably coupled together, is available from Teledyne, of Hawthorne, Calif.

The embodiment of the invention illustrated in FIG. 2 shows a single non-imaging optical focusing device 44 for the array 32 of dies. In accordance with another aspect of the present invention, it is anticipated that multiple non-imaging optical focusing devices might be utilized. For example, referring to FIG. 2A, substrate 34a may include multiple groups of dies, 30a, 30b, which are arranged on the substrate 34a to operate as separate groups of light-generating elements. To that end, a non-imaging optical focusing device 44a may be associated with one group of dies 34a, while another non-imaging optical focusing device 44b may be associated with dies 30b of the other group. Of course, greater numbers of non-imaging optical focusing devices may be utilized for other discrete groups of dies. Generally, however, there will be a substantially smaller number of non-imaging optical focusing devices than there are individual dies. That is, in the embodiments of the invention illustrated in FIGS. 2 and 2A, a single non-imaging optical focusing device will serve a multiple number of individual light-emitting dies. The multiple focusing devices will cooperate to transmit light along axis 51.

In accordance with another aspect of the present invention, the barrel portion 16 of the device 10, particularly the distal or radiating end 17 of the barrel portion, is inserted into the mouth of the patient for curing compound therein. Accordingly, before use with the next patient, it will be appreciated that the device would have to be sterilized. Prior art devices must be sterilized, such as by autoclaving, as mentioned above, which further complicates and delays the curing procedure. The present invention provides a unique construction which eliminates the requirement of a sterilization process and thereby makes the curing process simpler, quicker, and more cost-effective.

To that end, the invention utilizes a removable sleeve which may be separately autoclaved. Alternatively, as mentioned, the sleeve may be disposable to be discarded after one use. Specifically, in the embodiment of the invention illustrated in FIGS. 1 and 2, the ring structure 43 forming reflective surface 42 and the adjacent non-imaging lens 44 are mounted and secured within a disposable sleeve 50. The sleeve 50 is made of a suitable disposable plastic, such as PVC, and the sleeve is configured for being positioned over at least a section of the barrel portion 16 of the device 10. Preferably, the sleeve is configured to extend over a significant section of the barrel portion 16, and at least over the part of the barrel portion 16 exposed to the mouth of a patient. In the embodiment illustrated in FIG. 2, the PVC sleeve 50 is configured to be positioned over the heat tube 38 and array 32. The sleeve 50 is configured to position the lens 44 and reflective surface coaxially with the array 32. In one embodiment of the invention, once the device has been used for curing, the PVC sleeve 50, ring structure 43, and non-imaging lens 44, may then be removed from the heat tube and away from the array 32 of light-emitting dies. The sleeve, including the lens and reflective structure 43 are then discarded with the sleeve 50. Alternatively, the sleeve and

US 7,066,733 B2

11

lens and reflective structure could be removed and autoclaved and then placed back in position.

In an alternative embodiment, only the sleeve might be disposable. The lens 44 and ring structure would then remain with the array 32 or could be separately positioned with the array apart from sleeve 50. In such a case, only the sleeve would be discarded or autoclaved.

The device and the component parts, including the heat tube 38, heat sink 36, substrate 34, and dies 32, are not been directly exposed to a patient because they are covered by the sleeve. In the embodiment where the lens and structure 43 are separate from the sleeve, those parts will be isolated as well. Therefore, the isolated or covered components do not have to be sterilized or autoclaved as required with prior art devices and methods. Thereafter, a new sleeve, possibly including a new reflective structure 43 and lens 44, is inserted onto the heat tube 38 and barrel portion 16 and aligned with the array of dies 32 for the next use. The present invention therefore reduces the possibility of contamination between dental patients and further enhances the curing method by eliminating the sterilization process. As a result, the curing process is simpler and more efficient because a sterilization step is not necessary between patients. The process is also more cost effective as autoclaving equipment does not have to be purchased and operated to sterilize the curing light.

The present invention as illustrated in FIG. 2 also improves upon the prior art by delivering a beam of light from a source close to the work surface (e.g., a tooth). Specifically, the distal or radiating end 17 of the barrel portion 16 is positioned at or proximate a tooth surface containing the curable compound. With the light delivered directly from the array 32 to the surface through only the non-imaging lens 44, numerous lossy air/glass interfaces are eliminated between the die array 32 and the output surface 49 of the device 10. Conventionally, the light generating elements have been positioned away from the work surface and inside the housing such that a fiber optic light guide was necessary to transmit the light to the work surface. Furthermore, with such light guides, it is often necessary to use a converging optical lens before the light guide so that the generated light may be efficiently focused into the input end of the light guide. Light guides and converging lenses present lossy air/glass interfaces to the light beam. It has been estimated that air/glass interfaces may produce light power losses in the range of approximately 10% per interface. By eliminating the interfaces between the dies 30 and the tooth surface, the present invention light transmits light in an efficient, collimated form with less of the power loss at the various interfaces that are required in the prior art. Therefore, the present invention provides efficient transmission of a collimated light beam to the work surface of the tooth and curable compound thereon. With more efficient transfer of light, a smaller number of dies 30 in the array 32 may be used while still providing a sufficient light intensity or light power density at the output surface 49 of the lens. In that way, the invention may provide suitable curing power levels in a generally compact and easily manipulated device. Furthermore, with less loss at the interface, less heat is generated, further improving on the prior art.

In the preferred embodiment of the invention, the dies 30 are positioned in the array 32 with a density sufficient to provide a light power output density at the desired wavelength in the range of approximately 200–1400 mW/cm². In one embodiment of the invention, the dies are generally square in shape, and are 0.010 inches per side. The dies are spot welded to the substrate and specifically to leads (not

12

shown), which are electrically coupled to a control circuit 24 and/or power supply 20. The die substrate is preferably is circular, having a diameter of approximately 0.19 inches (approximately 4.8 millimeters).

A suitable number of dies are positioned on substrate 34 to generate the desired light and power density at the output surface 49 of the non-imaging optical focusing device 44. Generally, in one embodiment of the invention, 30–60 dies are suitable for generating desirable curing light power densities. Of course, a greater or lesser number of dies may be utilized in other embodiments of the invention.

Because of the unique cooling arrangement of the present invention utilizing conductive cooling, the reduction of lossy interfaces and the overall configuration of the embodiment of the invention disclosed herein, the dies may be driven at a sufficient power level to yield the desired light power output or light density, in the range of approximately 200–1400 mW/cm². Generally, the dies may be driven by 12 volts DC in series sets of 3 dies.

For example, one embodiment could be a 34 die lamp which may be operated at 8.13 Watts (8.7 V and 0.935 A). Such a design proved efficient and performed a suitable job of curing. Another embodiment might use 60 die or a higher power output (e.g., a 67% increase in power).

In one embodiment of the invention, series groups of three dies are connected in series to a 12 Volt DC source through a current-limiting resistor. To that end, each die is then driven with approximately 4 volts DC. Furthermore, by utilizing a 12 Volt source, the fan may also be driven by that DC source. It may be readily understood that other arrangements of dies may be utilized, driven by sources having various different power or voltage output levels.

Preferably, the dies 30 are positioned in the array 32 in a sufficient density to provide a curing light which has a suitable light power output for proper curing, but which does not overheat tissues surrounding the work surface, such as a tooth. The inventive lamp will provide less heat to the tissue than a halogen lamp. For example, an embodiment with 34 die as described above yielded a radiometer reading of 200 mW/cm², while a comparable cure with a 52 Watt halogen lamp yielded readings around 600 mW/cm². Because of the much lower radiometer readings, tissue damage should not be as significant an issue with the invention as with a halogen light.

With current dental applications, it is desirable to utilize a die array 32 which generates blue light in a wavelength range of approximately 130 nanometers to 470 nanometers because current compounds are sensitive to blue light. While such blue light is suitable for current dental applications, the present invention is not limited to only blue light wavelengths for curing purposes. Rather, the present invention may be utilized with compounds that may cure utilizing light at other various wavelengths.

Furthermore, the non-imaging optical focusing device 44 may be sized appropriately depending upon the application. For example, a lens having an 8 millimeter cross-sectional diameter at the output surface 49 may be utilized for small curing applications, whereas a lens having a cross-sectional diameter of 11 millimeters at surface 49 might be utilized for larger curing applications. As may be appreciated, to ensure efficient transfer of curing light to the work surface, it is desirable that a majority, if not all, of the light generated by the dies of array 32 is transmitted into and out of the non-imaging optical focusing device 44. To that end, the reflective surface 32 is shaped and configured in diameter to ensure that the light beam is collected and reflected into the input end 45 of the optical focusing device 44. In the

US 7,066,733 B2

13

illustrated embodiment, the output end 51 of the reflective surface which interfaces with the input end 45 of the optical focusing device is smaller in diameter than the input end 45. In that way, the light reflected by surface 42 is captured by the optical focusing device 44. The non-imaging optical focusing device 44 is not restricted by a focal length, since it is a non-imaging device. In that way, the device 44 captures and collimates the light beam for efficient transmission to a work surface, such as a tooth. Therefore, the present invention is not particularly sensitive to the distance which the output end 49 is maintained from the tooth surface. Of course, it is generally desirable to position the output end 49 as close to the tooth surface as possible for efficient curing.

In accordance with another aspect of the invention, the dies 30 might be evenly arranged on substrate 34 to form a generally circular array, as illustrated in several of the embodiments disclosed in U.S. patent application Ser. No. 09/009,205, and as illustrated in FIG. 2B. The dies might also be mounted in various groupings, such as subgroups of four or some other number, and then such subgroups would be mounted on the substrate. That is, sub groups of multiple dies could be individually mounted and electrically coupled together, and subsequently the subgroups could be mounted on the substrate with other subgroups. As such, the invention would not be limited to individual mounting of all of the dies.

FIG. 3 illustrates another embodiment of the invention wherein the die array is also positioned proximate the distal, or radiating end 17 of the barrel portion 16 of the housing. In the alternative embodiment, the structure is somewhat similar to the device 10 illustrated within FIGS. 1, 2, and 2A, with a different construction at the distal or radial end 17, as illustrated in FIG. 3. Specifically, the alternative embodiment utilizes an array of dies 60 mounted on a substrate layer 62. The substrate layer could be sapphire or diamond which has suitable thermally conductive properties for heat dissipation while remaining electrically insulated. Substrate 62 is then bonded to a heat sink 64 which may be made of a suitable material, such as copper. The die array 60 and the assembly including the substrate 62 and heat sink 64 are then welded or soldered onto an end of a liquid-filled heat tube 66, which conductively transfers heat away from the heat sink. In that way, the alternative embodiment of the invention utilizes the advantages provided by the above-discussed embodiment, due to the conductive cooling of the substrate and die array. As illustrated in FIG. 1, the opposite end of the heat tube 66 is coupled to the heat exchanger 26 which is convectively cooled, such as by a fan 28.

To focus light from the die array 60 in an efficient manner into a collimated and focused light beam, the embodiment of the invention shown in FIG. 3 utilizes a total internal reflection, or TIR lens. TIR lenses are known (e.g., U.S. Pat. No. 4,337,759) and are commercially available, such as from TIR Technologies, a division of Teledyne. TIR lenses are more efficient than typical Fresnel lenses, and provide a collimated beam of light generated by the die array 60. The TIR lens structure 68, shown in FIG. 3, utilizes a series of saw-tooth surfaces 69 for collimating light from the array 60 at various different angles into a beam of light 70 focused in a direction generally perpendicular to the plane of the array, as illustrated by reference numeral 70. In that way, light from the array may be efficiently delivered to a curable compound on a work surface. Preferably, the TIR lens is a non-imaging optical focusing device. The lens 68 is appropriately arranged to be generally coaxially aligned with array 60 for efficient light transmission.

In accordance with one aspect of the present invention, the TIR lens 68 is formed of a suitable polycarbonate. As

14

discussed above, lens 68 may be incorporated with a disposable sleeve 72 positioned around the heat pipe 66. When an application is complete, the sleeve 72 and TIR lens 69 may be removed and discarded, thus eliminating the need to further sterilize or autoclave the device 10. Alternatively, lens 68 may be separately positioned with respect to sleeve 72 to be separately discarded or to remain with the array 60. The embodiment illustrated in FIG. 3 further provides efficient delivery of light from the die array to a work surface because the die and lens are positioned at the radiating or distal end 17 of the barrel portion to be directly adjacent to the work surface. In that way, various air/glass interfaces are eliminated to reduce power losses associated with such interfaces, as discussed above.

The array 60 of LEDs might be arranged and dimensioned similarly as discussed above with respect to the embodiment illustrated in FIG. 2. The TIR lens 68 will generally have a circular cross-sectional diameter significantly greater than the circular cross-sectional diameter of the array in order for the lens to capture light which is generated by the array at very small angles with respect to the plane of the array 60. In the embodiment illustrated in FIG. 3, a reflector is not utilized between the die array 60 and the lens 68. Therefore, the lens must be sized appropriately to capture low angle light, such as that illustrated by reference line 73.

FIG. 4 illustrates an alternative embodiment of the invention in which the die array is positioned more centrally within the housing and spaced rearwardly from the barrel portion. Specifically, a die assembly, similar to that illustrated in FIG. 2, is mounted in the housing proximate the proximal end 19 of the barrel portion. The substrate 34 is then coupled directly to the heat exchanger 26, which may be convectively cooled, such as by a fan 28. The barrel portion 16, rather than housing a heat tube, houses a light pipe or light guide 76. Such light guides are commercially available and come in a variety of different sizes. Generally, such light pipes are formed of a plurality of optical fibers (for example, approximately 5,000 fibers which are fused into a single light pipe structure). The beam of light transmitted into the input end 77 located at the proximal end 19 of the barrel portion 16, is transmitted through the light pipe and is directed out the transmission end 78 of the pipe at the distal end 17 of the barrel portion 16. The light pipe may maintain uniform diameter from the input end 77 to the output or transmission end 78, or may taper from one diameter to a smaller diameter at the transmission end 78. Preferably, the light pipe is bent to follow the bent barrel portion 16, illustrated in FIG. 4, so that the beam of light is directed downwardly, such as into the mouth of the patient. Alternatively, the light pipe itself may form part of the barrel portion and may be attached to the housing 12, such as by being screwed into the housing.

The non-imaging optical focusing device, such as a non-imaging optical lens 44, is used to focus the light into the light pipe. The input end 77 of the light pipe is dimensioned appropriately so that light is efficiently delivered through the focusing device 44 to the light pipe 76. To that end, the focusing device 44 collimates the light so that it does not diverge beyond the input end 77 of the light pipe.

Generally, light pipes have a defined angle of acceptance at their input end 77, such as 40°. Light directed outside of that acceptance angle is not captured by the light pipe and transferred to the work surface. The reflective surface 42 and non-imaging optical focusing device 44 utilized in the embodiment in FIG. 4 are designed to generate a beam of light which does not diverge more the acceptance angle of the light pipe. In that way, energy is efficiently translated from the array which outputs light in generally a 180° angle. Therefore, the present invention utilizes a non-imaging optical focusing device which collimates light from a 180°

US 7,066,733 B2

15

light output source to a column which does not diverge more than the acceptance angle of the light pipe to which the light is input.

In still a further embodiment of the invention, the die array and the TIR lens structure similar to that shown in FIG. 3 might be utilized within the housing as shown in FIG. 4. To that end, the die array 60, substrate 62, and heat sink 64 are coupled to the appropriate heat exchanger, which is then convectively cooled, such as by a fan. In such an embodiment, as well as in the embodiment illustrated in FIG. 4, device 10 would generally have to be sterilized or autoclaved after each use. However, since the die array and optical focusing devices are positioned inside the handle portion of the housing, they would be protected from the high temperatures associated with such sterilization.

Alternatively, as illustrated in FIG. 4, a disposable sleeve 82 might be utilized with the embodiment to cover the light pipe. The disposable sleeve 82 may be discarded with each use, thus effectively eliminating the required autoclaving step.

While the present invention has been illustrated by the description of the embodiments thereof, and while the embodiments have been described in considerable detail, it is not the intention of the applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details representative apparatus and method, and illustrative examples shown and described. Accordingly, departures may be made from such details without departure from the spirit or scope of applicant's general inventive concept.

The invention claimed is:

1. An instrument for curing light-curable compounds which are curable in the mouth of a patient, the instrument comprising:

a housing;

a plurality of solid state, light-emitting elements, the elements comprising semiconductor junctions and being mounted on a substrate supported by the housing to form a collective array on said substrate, the array of elements operable for collectively emitting light having wavelengths within a narrow band of wavelengths;

a generally clear layer simultaneously covering all of the plurality of light-emitting elements for protecting the array of semiconductor junctions;

an optically reflective element coupled to surround the plurality of light-emitting elements to capture the collective light from the array of light-emitting elements and direct it forwardly away from the collective array and ultimately to a compound for curing.

2. The instrument of claim 1 wherein said solid state elements are light emitting dies formed of a semiconductor material.

3. The instrument of claim 1 further comprising a heat sink thermally coupled to the substrate for absorbing heat generated by the array of elements.

4. The instrument of claim 1 further comprising a thermally conductive element which is thermally coupled to the substrate for conductively transferring heat generated by the array of elements away from the substrate.

5. The instrument of claim 1 further comprising a heat exchanger which is thermally coupled to the substrate for dissipating heat generated by the array of elements.

6. The instrument of claim 1 further comprising a first heat sink element thermally coupled to the substrate for absorbing heat generated by the array of elements, and a heat

16

exchange element thermally coupled to the heat sink for conductively transferring heat generated by the array of elements.

7. The instrument of claim 1 wherein said housing comprises a barrel portion having a proximal end spaced from a distal end of the barrel portion, the distal end being configured to be placed in the mouth of a patient, the array of light-emitting elements being positioned proximate to said proximal end, a light transmitting device being operably coupled to said array for transmitting the light beam from the array to the housing distal end.

8. The instrument of claim 7 wherein said light transmitting device comprises a plurality of fiber optic elements operably coupled together for directing said beam.

9. The instrument of claim 7 wherein said light transmitting device has an acceptance angle, said optical focusing device operable for generating a beam of light which does not diverge significantly from said acceptance angle.

10. The instrument of claim 9 wherein said array of light-emitting elements emits light in the range of 0°-180° and said optical focusing device is operable for collimating the light into a beam which does not diverge significantly from said acceptance angle.

11. The instrument of claim 1 further comprising a portable power supply positioned within said housing for portable operation of the instrument.

12. The instrument of claim 1 wherein said array of elements has a density of elements on the substrate operable for collectively emitting a power density of light in the range of 200 to 1400 mW/cm².

13. An instrument for curing light-curable dental compounds, the instrument comprising:

a light-emitting element having a plurality of generally bare semiconductor junctions positioned together to form multiple light emitting surfaces on a substrate and operable for collectively emitting light having wavelengths within a narrow band of wavelengths suitable for curing dental compounds;

a generally clear protective layer simultaneously covering the plurality of semiconductor junctions for protecting the junctions, the light generated by the light-emitting element passing through the protective layer;

an optically reflective element coupled to surround the light-emitting element and protective layer and operable to capture the light generated by the light-emitting element and direct it generally forwardly.

14. The instrument of claim 13 further comprising a light transmitting device being operably coupled to the light-emitting element for transmitting the light emitted by the element toward a curing site.

15. The instrument of claim 13 further comprising a plurality of heat dissipating elements mounted behind the substrate holding the semiconductor junction for conductively transferring heat generated by the junction.

16. An instrument for curing light-curable dental compounds, the instrument comprising

a first plurality of light-emitting elements, the first elements comprising generally bare semiconductor junctions forming a collective array operable for collectively emitting light having within a narrow band of wavelengths suitable for curing a dental compound;

a second plurality of light-emitting elements, the second elements comprising generally bare semiconductor junctions forming a collective array operable for collectively emitting light within a narrow band of wave-

US 7,066,733 B2

17

lengths suitable for curing a dental compound and
operating separately from the first plurality of light-
emitting elements;
a generally clear protective layer covering the semicon-
ductor junctions of at least one of the pluralities of
light-emitting elements for protecting the junctions,
light generated by the plurality of light-emitting ele-
ments passing through the protective layer;
an optically reflective element coupled to surround at least
one of the pluralities of light-emitting elements and
operable to capture the light generated by the plurality
of light-emitting elements and direct it generally for-
wardly.

18

17. The instrument of claim 16 further comprising a
generally clear protective layer covering the semiconductor
junctions of both pluralities of light-emitting elements for
protecting the junctions, light generated by the plurality of
light-emitting elements passing through the protective layer.

18. The instrument of claim 16 further comprising an
optically reflective element coupled to surround both plu-
ralities of light-emitting elements and operable to capture
the light generated by the pluralities of light-emitting ele-
ments and direct it generally forwardly.

* * * * *